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GEORGIA INSTITUTE OF TECHNOLOGY

School of Mechanical Engineering

Atlanta, Georgia

PROGRESS REPORT
PHASE I

LARGE GAS TURBINE WHEELSPACE COOLING STUDIES

G. E. SERVICE AGREEMENT
P. O. #087-ETEL-71225

by

Ward O. Winer
Professor
and
Principal Investigator

David M. Sanborn
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Schenectady, New York 12345

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Atlanta, Georgia

PROGRESS REPORT
PHASE I
SUMMARY

LARGE GAS TURBINE WHEELSPACE COOLING STUDIES

This report describes a facility to simulate turbine wheelspace cooling characteristics of General Electric medium and large gas turbines and contains some preliminary data obtained. The system is capable of operating with hot rim flow which is turned in a manner simulating actual machine behavior. It has been found that hot gas inflow to the wheelspace results in part from circumferential variations in the rim flow and persists even to relatively high net outward cooling flow passed the seals.

Ward O. Winer
Principal Investigator

Stothe P. Kezios, Director
School of Mechanical Engineering

October, 1976

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I. INTRODUCTION

The objective of the efforts reported here was to develop a facility to simulate wheelspace cooling characteristics of General Electric medium and large gas turbines, and to obtain preliminary data with the facility. The wheelspace cooling development program of which this work is a part is summarized in a General Electric Memorandum by R. F. Hoeft dated October 1, 1974. The historical perspective of the program is presented in that memorandum and the references listed in it.

The objectives of the wheelspace cooling program are:

1. To provide a working curve for establishing cooling flow requirements on actual designs.
2. To evaluate different seal and wheelspace configurations that have not been previously evaluated.
3. To continue efforts towards understanding the fluid dynamics of this system to allow predicting the effect of parameters not anticipated in this program.

The work reported here is the first phase of a continuing effort to meet the above objectives.

The facility developed consists of a 40 inch diameter wheel without buckets in a casing which has stationary blades to simulate nozzle flow and the turning of flow over the wheel rim. Heated mainflow is provided which simulates actual turbine mainflow velocity in both magnitude and direction. Cooling flow to both forward and aft wheelspaces can be varied. Both forward and aft stator-wheel spacing can be varied. Wheel speed can be varied continuously up to 3000 RPM. Several interchangeable wheel and stator seal pieces are available.

The instrumentation consists of flow measurements of forward and aft cooling flows, and main flow as well as 54 thermocouples and 44 static pressure taps.

The preliminary test program reported consisted of a series of experiments on a single seal configuration with varying wheel speed and cooling flows. The preimary result was the observation that circumferential variations in the mainflow cause circumferential variations in seal flow which could not be adequately determined with the original pressure and temperature sensors. Increased instrumentation density circumferentially in the facility verified this observation. The source of the circumferential variation in the mainflow is the mainflow inlet port distribution on the apparatus.

II. THE EXPERIMENTAL FACILITY

The test apparatus consisting of the rotor, the housing, and seals were supplied by General Electric. Instrumentation, drive train and plumbing were supplied by Georgia Tech.

A. Wheelspace Apparatus:

The wheelspace apparatus is shown in five photographs in Appendix B and the five mechanical drawings for it are reproduced as foldouts in Appendix C.

A 40 inch diameter, balanced rotor with fore and aft rotating seals was mounted on permanently lubricated rolling element bearings in the walls of the housing. No rotating buckets were attached to the wheel. Simulated crossflow was provided through fifteen discrete openings to an annular flow space surrounding the rotor. Stationary buckets at the axial position of the wheel, and nozzles upstream of the wheel provided for a flow direction at the rim openings comparable to operating turbine wheels. A plenum was included upstream of the nozzles to smooth the stagnation pressure distribution arising from the crossflow entrances. Crossflow was exhausted directly to the atmosphere from ten openings in the housing. Nozzles and buckets were mounted in a half-ring which may be removed for inspection of rim and seal spacings.

Axial rotor-to-rim spacing was adjustable through jack bolts in the housing wall and was independent of inner wall to rotor spacing (also adjusted with jack bolts). Stationary seals were mounted to the fore and aft inner walls to interact with the rotating seals with a clearance regulated by shims and set screws. Seal overlap was changed by employing stationary seals of varying width.

Cooling through-flow was introduced to the wheelspace through three openings in each the fore and aft sides. No adjustment of the wheelspace wall to rotor spacing was provided.

The rotor shaft was attached through a Lovejoy flexible coupling to a drive shaft running beneath a propane fueled Chrysler industrial engine fitted with an electronic speed limiter. The engine and drive-shaft were connected by a belt and a hand operated dry clutch. The drive shaft was supported by two pillow blocks. The belt drive also acted as a torque limiting device. Rotor speed was measured by a mechanical tachometer held against the rotor shaft or from calculation using belt reduction ratio and engine RPM measured by an electronic tachometer on the engine ignition.

Crossflow was supplied by a Worthington two-stage piston air compressor at four pounds per sec. The air passed through a combustion chamber before entering the distribution hoses to the rotor housing. An air-propane mixture was electrically ignited in the combustion chamber to provide an exit temperature of 250F. Combustion was controlled pneumatically by a Taylor Instruments Temperature Controller. A flame-out sensor and low air/propane pressure switches were provided for safety.

Air flow rate to the burner was measured with an orifice plate flowmeter upstream of the runner and air flow control valve which was opened full for all tests. Pressure was measured at the same location. Fifteen reinforced rubber hoses provided distribution of cross flow to the housing.

Cooling through-flow was provided at up to 1.3 pounds per sec from a 10 hp electric centrifugal blower through three ducts on the fore and aft sides of the housing. The rate of cooling air flow was measured with orifice plate flowmeters in each of the two pipes leading to the ducts. In this way fore and aft flows were measured separately. Total cooling air flow was regulated by restricting the inlet of the blower. A thermocouple in one inlet pipe was used to indicat cooling inlet temperature.

B. Instrumentation:

Housing instrumentation consisted of 44 static pressure taps and 54 copper-constantan thermocouples concentrated at three circumferential positions. The instrumentation was distributed radially in three positions along the wheelspace wall and radial seal area, and axially along the crossflow space. In addition three radial positions were included for wheelspace thermocouples both fore and aft. The instrumentation sensor locations are shown in Figure 1 and 2.

The static pressures were read on a common-well manometer with reference to atmospheric pressure. The temperatures were obtained by connecting the thermocouples to a Leeds and Northrup multipoint recorder. Table I indicates the relationship between recorder position and thermocouple location.

Twelve of the pressure taps were only installed for the last two tests - M and N. These were placed in pairs circumferentially on the outer cross flow surface to detect circumferential variations in the cross flow.

Table I. Thermocouple Identification - December 15, 1975

Recorder Bank	T/C	MACHINE LOCATION	Bank	T/C	LOCATION
1	2	E73	4	1	C11
	2	D71		2	C31
	4	C01		3	B61
	5	C74		5	B63
	6	C71		6	B64
	7	C84		7	B51
	8	C81		8	B53
	9	E81		9	B41
	10	E83		10	B43
	11	D81		11	B44
	12	F71		12	B31
2	1	F73	5	1	B33
	3	A71		2	B21
	4	B71		3	B23
	5	B74		4	B24
	6	F81		6	B11
	7	B81		7	A01
	8	F83		8	D01
	9	B84		9	B03
	10	A81		10	C03
	11	E71		11	B01
	12	C44		12	
3	1	C64	6	1	B04
	2	C63		2	C04
	4	C61		3	
	5	C53		4	
	6	C51		5	
	7	C43		6	
	8	C41		7	
	9	C33		8	
	10	C24		9	
	11	C23		10	AMBIENT
	12	C21		11	CROSS INLET
				12	COOLING INLET 1/16/76

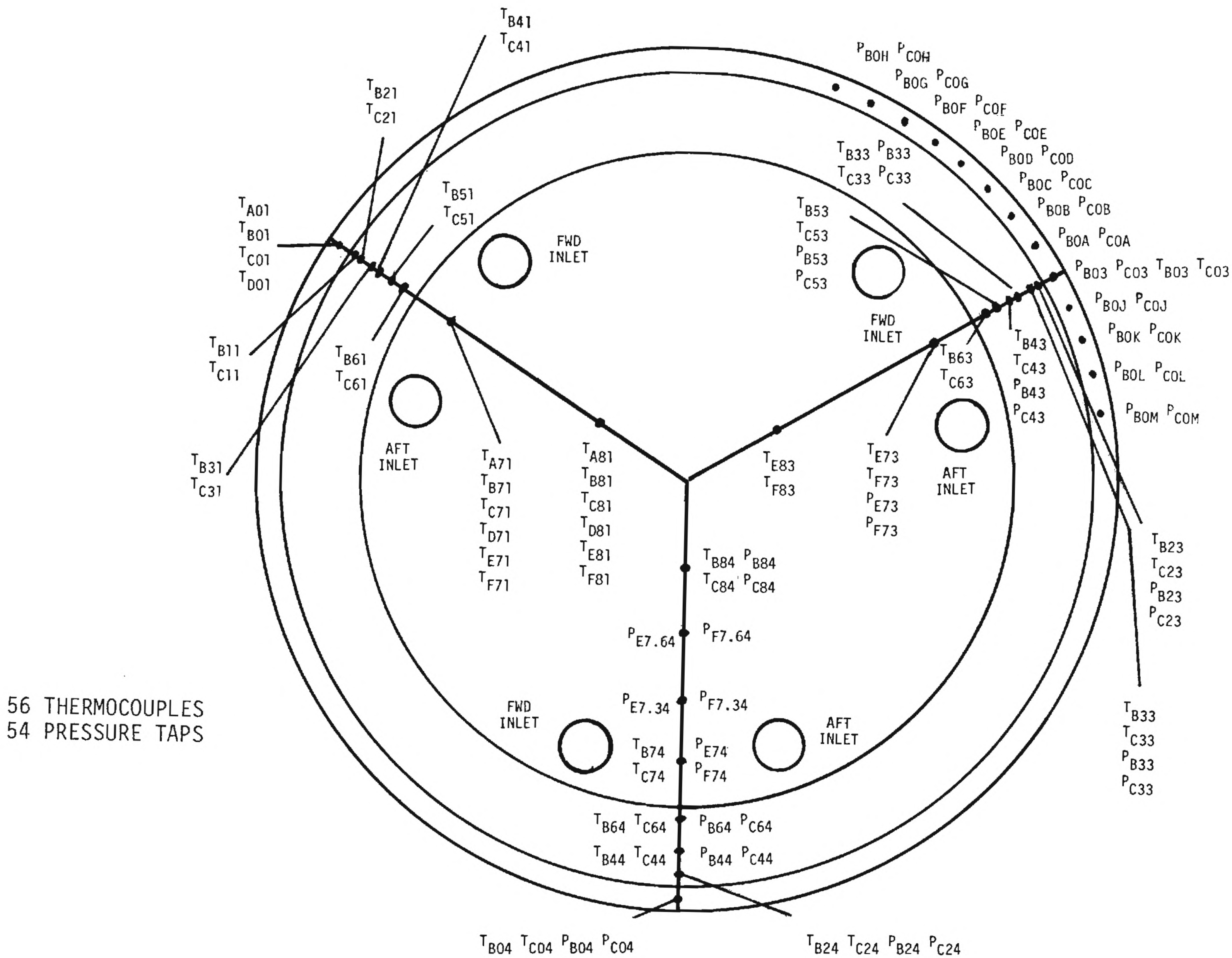

Figure 1. Instrumentation (Viewed from Aft End)

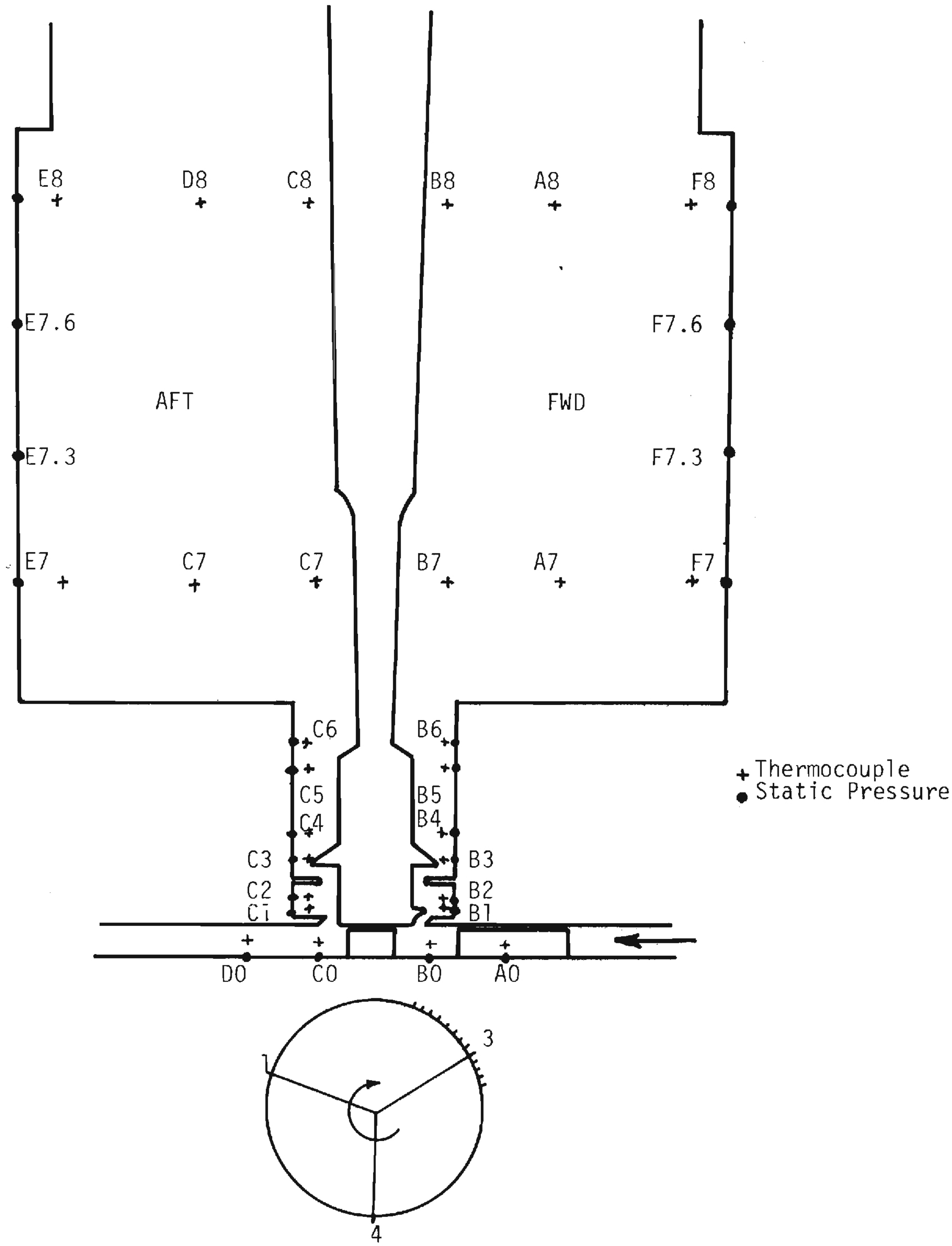

Figure 2. Instrumentation.

III. TEST PROCEDURE

Only steady state data were of interest in this study. The procedure was to start the compressor and burner for the cross flow, the blower for the cooling flow and engine for wheel rotation. When hot cross flow was employed the thermal transient of the system was the controlling factor to determine when steady state was reached. The temperatures as read on the multipoint recorder were used to determine steady state. When cold cross flow was used the wheel speed and pressures as indicated by the heights in the manometers were used to determine steady state. In this case steady state was reached in one to three minutes. Once steady state was reached the manometer readings and flowrates were recorded, and the temperatures automatically recorded.

In the set of tests reported the crossflow (4.0 lbm/s) and seal geometry were held constant. The seal geometry used is shown in Figure 3. The parameters varied were wheel speed, cross flow temperature, cooling flow rate and cooling flow entrance ports. Table II lists a summary of test conditions and readings taken. In all cases except test N the cooling flow fore and aft were measured - in run N there was no forced cooling flow but the parts were not blocked. In the cold cross flow tests temperatures were not recorded.

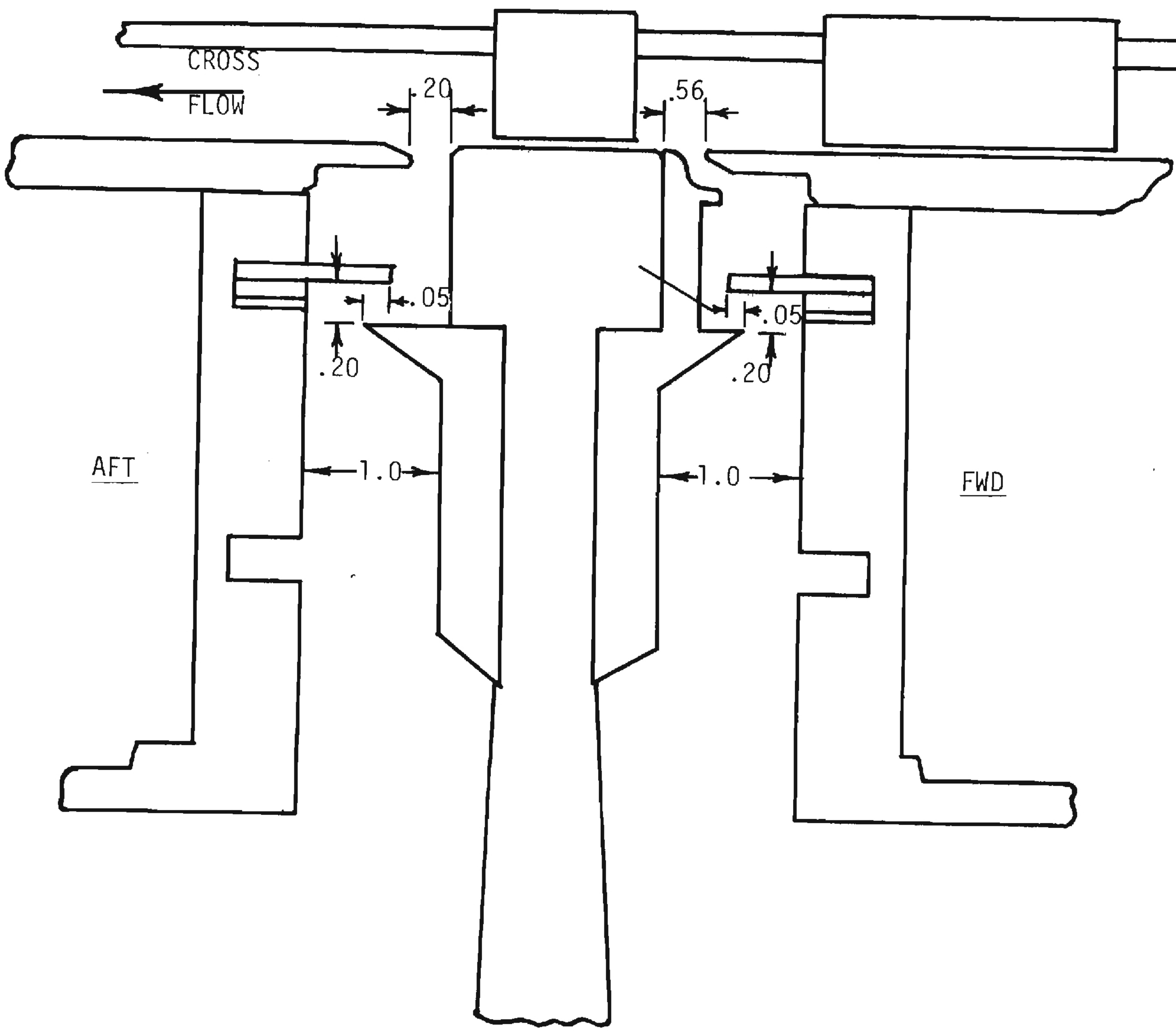

Figure 3. Baseline Configurations (Inches).

Table II. Summary of Tests Reported

Run No.	Conditions		Date Recorded[1]		Comments
	Cross flow temperature F	Wheel speed RPM	Pressure	Temperature	
B	250	2500	x	x	Varied fore and aft cooling flowrate
C	250	1000		x	Varied fore and aft cooling flowrate
D	250	2000		x	Varied fore and aft cooling flowrate
E	250	0	x	x	Varied fore and aft cooling flowrate
F	250	3000		x	Varied fore and aft cooling flowrate
G	250	3000	x	x	Varied fore and aft cooling flowrate
H	100	3000	x		Varied fore and aft cooling flowrate
I	100	2000	x		Varied fore and aft cooling flowrate
J	100	1000	x		Varied fore and aft cooling flowrate
K	100	3000	x		Partially blocked cooling flow inlets
L	250	3000	x	x	Partially blocked cooling flow inlets
M[2]	100	0	x		Varied fore and aft cooling flowrates
M_1[2]	100	2000	x		Varied fore and aft cooling flowrates
N[3]	100	0	x		No forced cooling flow

[1] in addition to flowrates.

[2] sixteen circumferential pressure taps added.

IV. TEST RESULTS AND DISCUSSION OF RESULTS

The data from all tests listed in Table III are given in Appendix A. The experiments were preliminary in nature and fall into two broad categories - baseline confirmation of system performance and search for sources of asymmetry in the system. Tests B-G were run with hot cross flow while varying the cooling flow and wheel speed. It became apparent from these runs that the pressure measurements were possibly the more sensitive and faster measure than hot gas inflow. The temperature measurements were influenced by conduction through the structure which resulted in long starting transients. Several unheated tests (H-J) were then performed in which temperatures were not recorded. These experiments permitted faster exploration for the origins of seal flow variations.

It became apparent from the above experiments that the hot gas inflow to the wheelspace was asymmetrically distributed and that the instrumentation was inadequate for measuring it in any detail. On the belief that the circumferential variations were the result of variations in the mainflow, twelve additional circumferentially placed pressure tape were installed in the mainflow outer surface. Experiments M and N were then conducted which confirm that the circumferential variations of pressure exist in the mainflow and that additional temperature and pressure sensors are necessary before further experiments are conducted.

In two experiments (K,L) the wheelspace cooling flow inlets were varied to determine if they were the source of the asymmetry in the seal flow. There are three inlets to each wheelspace and one or two were blocked to determine the effect on seal flow. These experiments

Table III. Cooling Flowrates - lbm/sec
(Cross Flow - 4 lbm/sec for all tests)

RUN	FWD	AFT	COMMENTS
B-1	–	–	INLET CLOSED
B-2	.21	.16	
B-3	.25	.30	
B-4	.27	.38	
B-5	.25	.31	
B-6	.225	.225	
B-7	.16	.113	
B-8	–	–	INLET CLOSED
C-1	.28	-.16	INLET CLOSED
C-2	.356	0.0	
C-3	.41	.178	
C-4	.46	.276	FULL INLET
C-5	.46	.276	1500 RPM
C-6	.406	.178	1500 RPM
C-7	.406	.178	COASTING
C-8	0	.225	FWD PLUGGED
C-9	0	.321	FWD PLUGGED
C-10	0	.414	FWD PLUGGED
C-11	0	.474	FWD PLUGGED
C-12	0	0.0	
C-13	0	.149	
C-14	0	.105	
D-1	.47	.29	
D-2	.425	.21	
D-3	.386	.14	
D-4	.34	0	
D-5	.26	-.16	
D-6	0	.36	FWD OFF
D-7	0	.46	FWD OFF
E-1	.47	.28	
E-2	.42	.20	
E-3	.39	.10	
E-4	.37	.06	
E-5	.36	0	
E-6	0	.40	FWD OFF
E-11	.65	.53	
E-12	.52	.37	
E-13	.47	.28	
E-14	.41	.18	
E-15	.39	.10	

RUN	FWD	AFT	COMMENTS
F-1	---	.38	FWD PLUGGED
F-2	.45	.28	
F-3	.40	.20	
F-4	.36	.10	
F-5	.32	0.0	
G-1	.618	.512	
G-2	.558	.443	
G-3	.520	.381	
G-4	.464	.321	
G-5	.381	.153	
G-6	.335	.554	
G-7	.273	.362	
H-1	.09	0	ONE FWD INLET
H-2	.205	.205	ONE FWD INLET
H-3	.275	.348	ONE FWD INLET
H-4	.320	.52	ONE FWD INLET
H-5	.35	.61	ONE FWD INLET
H-6	.665	.57	
J-1	.306	-.079	
J-2	.488	.316	
J-3	.699	.587	
J-4	.411	.158	
J-5	.775	.671	
K-1	.52	.40	ALL INLETS #1,3&
K-2	.69	.60	
K-3	.40	.22	
K-4	.55	.48	INLETS #1&3 FWD &
K-5	.46	.40	INLETS #1&3 FWD &
K-6	.31	.22	INLETS #1&3 FWD &
K-7	.31	.22	INLETS #3 FWD, 1 A
L-1	.42	.26	INLET #3 FWD, 1 AF
L-2	.40	.26	INLET #1&3 FWD & A
L-3	.53	.43	INLET #1&3 FWD & A
L-4	.57	.43	ALL INLETS
L-5	.46	.26	ALL INLETS
M-1	.10	-.24	NO FORCED COOLING
M-2	.69	.59	MAX COOLING
M_1-1	.10	-.21	NO FORCED COOLING
M_2-2	.68	-.60	MAX COOLING
N			NO FORCED COOLING

were inconclusive.

From experiments B-F the general trend of behavior can be seen. Figure 4 shows the effect of wheelspeed and cooling air flow on the air temperature in the aft cooling space just inside the seals. It appears from this figure that the wheel speed does not have a very influential role.

Figure 5 shows the effect of cooling air flowrate on both the fore and aft air temperatures in the wheel space at 3000 RPM. In retrospect it is thought that the system had not yet reached thermal equilibrium when these data were taken. However, the expected trend of wheelspace temperature decrease with increasing cooling flow is clear.

Upon examination of the data from the above experiments it became apparent that for net cooling flowrates of up to 0.2 lb /s there was still some locations around the seal where there was hot gas flow into the wheelspace. This can be seen by studying the pressure differential across the seal at the two locations instrumented as a function of net cooling flow in the wheelspace. This is shown in Figure 5 for run H. Figure 6 shows that up to a net cooling flow of 0.2 lb/s there is still flow from the rim into the wheelspace at circumferential location 3.

As a result of the above observation attention was directed toward determining the source of the circumferential variation in seal flow (or seal pressure drop). Several possible sources were considered - all related to the geometry of the apparatus. Experiments K and L were to determine the effect of cooling air inlet ports. The

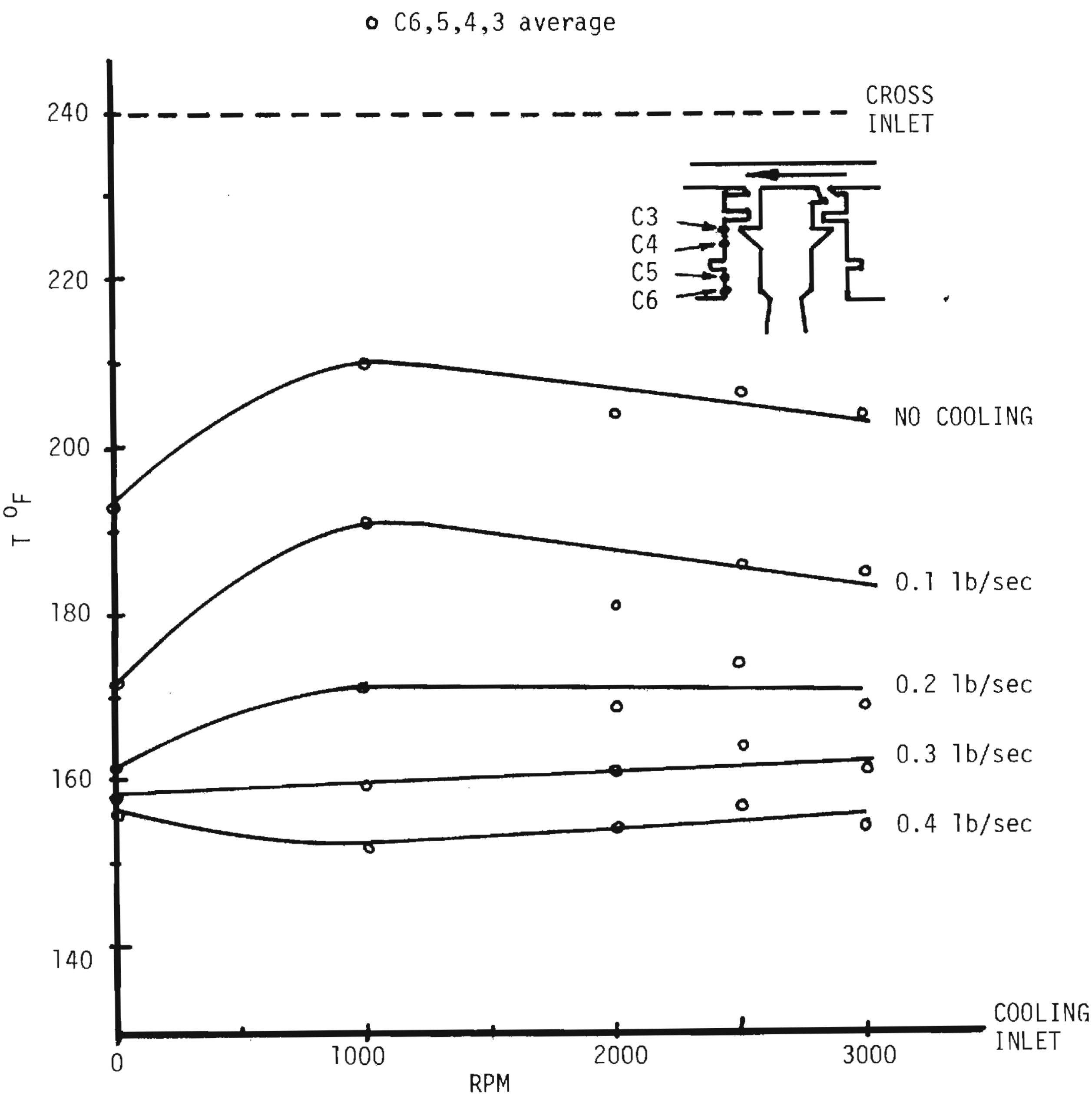

Figure 4 . Aft Temperature vs. RPM RUNS B-F.

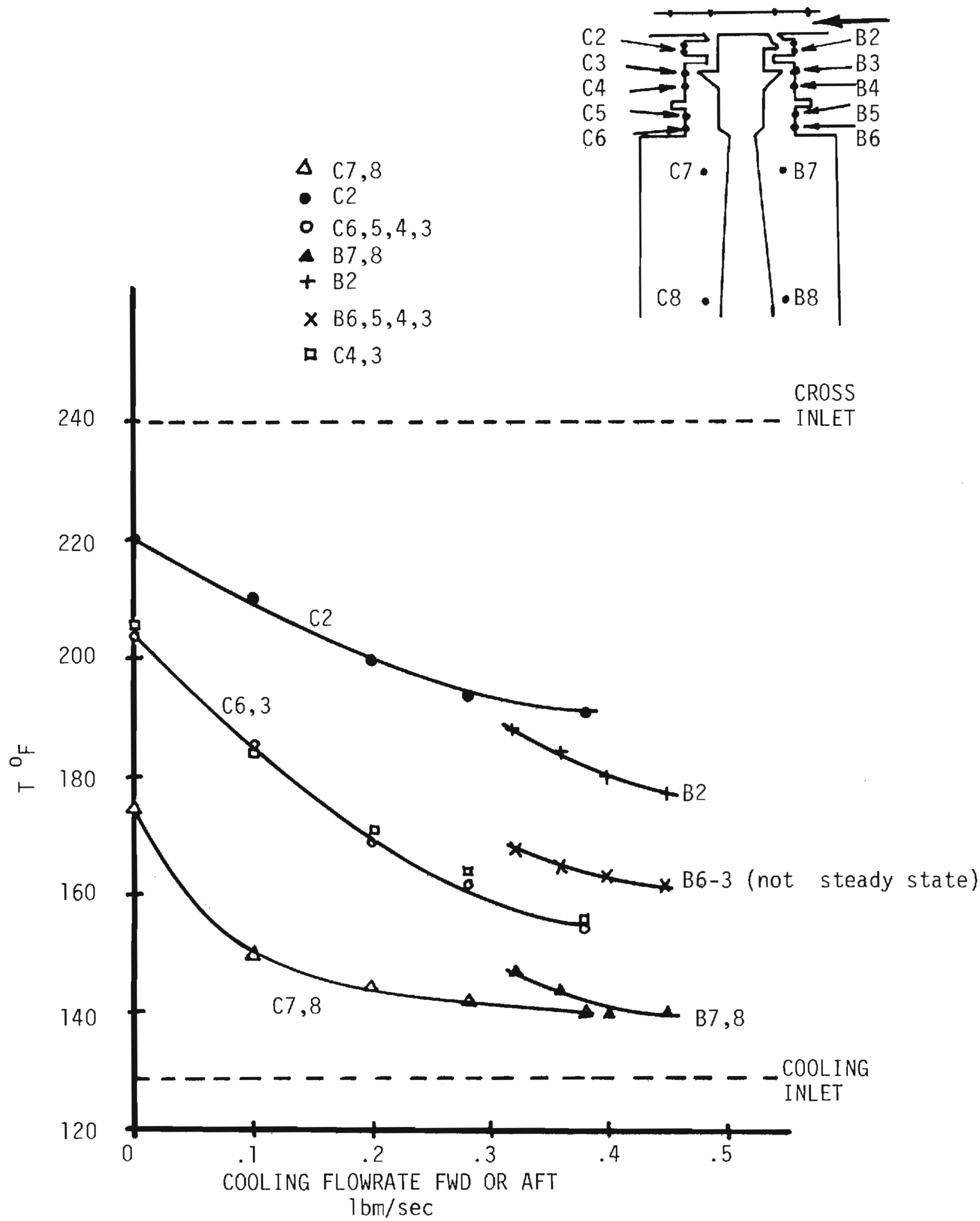

Figure 5 . Fwd and Aft Temperatures-3000 RPM.

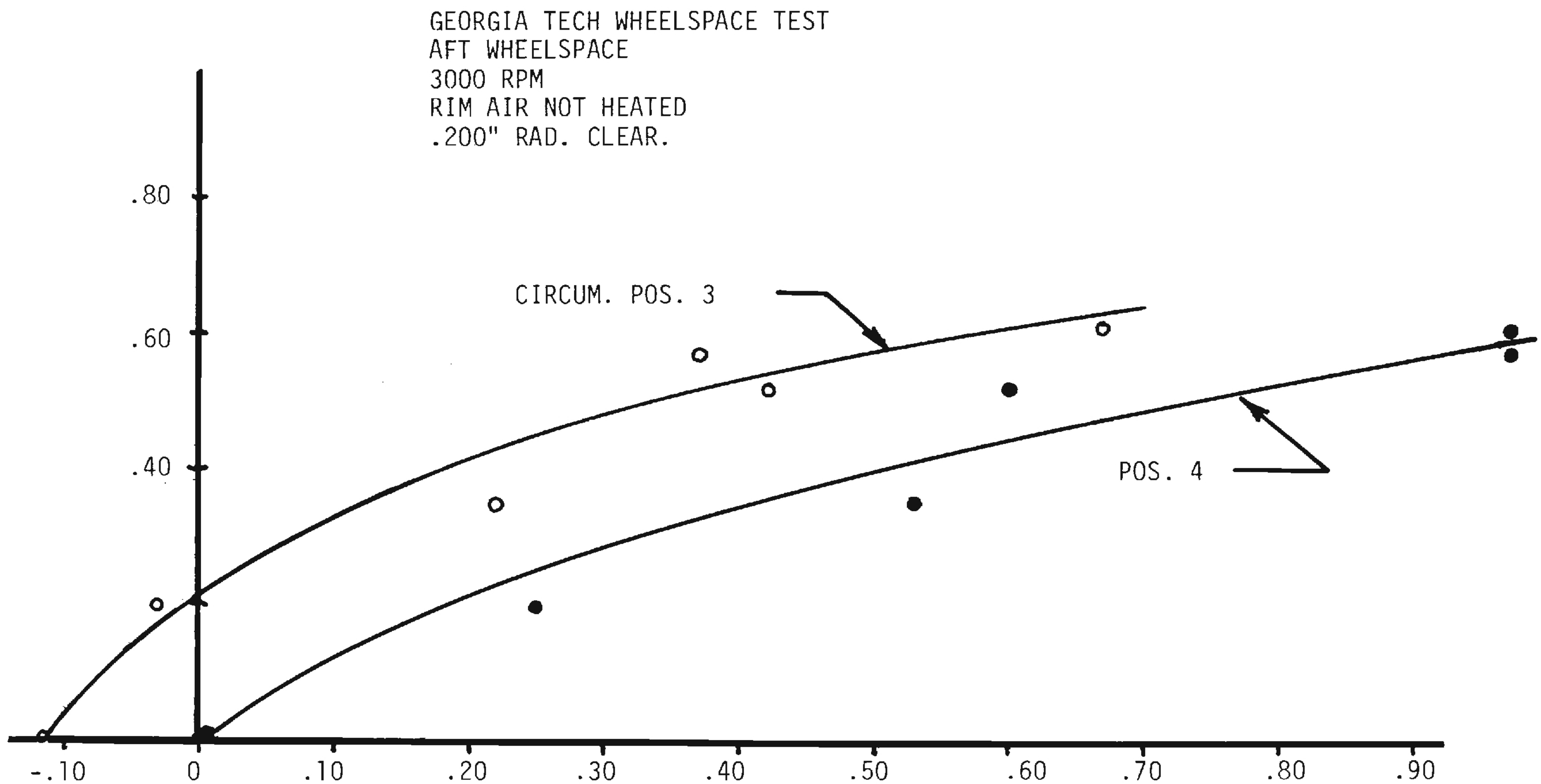

Figure 6. Pressure Difference Across Radial Seal

results were negative. Next circumferential variation in seal geometry was considered but ruled out because it was thought that it would cause the seal pressure drops to vary with wheelspeed which appeared not to be the case. (However, the effect of seal geometry was not thoroughly tested and its role can not be totally excluded.) The circumferential variation of the rim flow was considered next. This was a likely source of the flow variations because of the discrete inlets and outlets for the rim flow.

To assess the circumferential variation of the rim flow a series of sixteen static pressure taps were added in pairs adjacent to the original tape (#3) in the outer casing. Half the taps were located over the forward seal and half over the aft seal. They are located relative to the blades and the rim flow inlets and outlets as shown in Figure 7. Later four more pairs were added to the right of #3.

Figure 7 also shows the magnitude of the static pressure at each tap by the length of an arrow. These data are for no rotation of the wheel and no forced wheelspace cooling air. The datum, and the fore and aft wheelspace pressures, are also shown on the left hand side of the figure. The circumferential variation of the rim flow pressure is clearly seen to be dependent on blade location and rim inlet flow port. In the case shown, on the forward side there are locations where the flow is into the wheelspace and other locations where the flow is out of the wheelspace. On the aft side for the conditions shown the seal pressure drop varies but the flow is always into the wheelspace.

Figure 8 shows the same type of data as discussed above but for two wheel speeds (0 and 2000 RPM) and for two wheelspace cooling flows

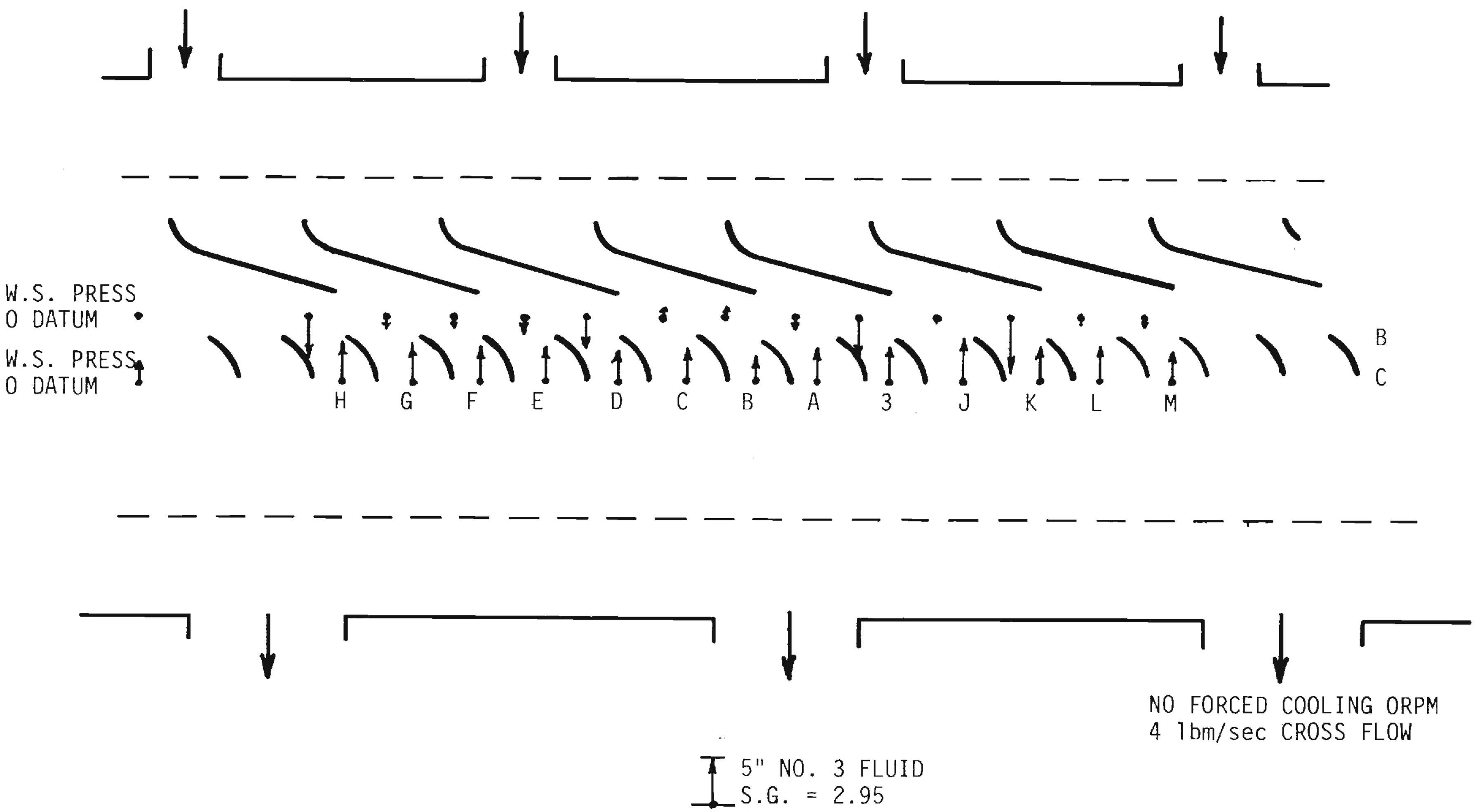

Figure 7. Cross Flow Pressures.

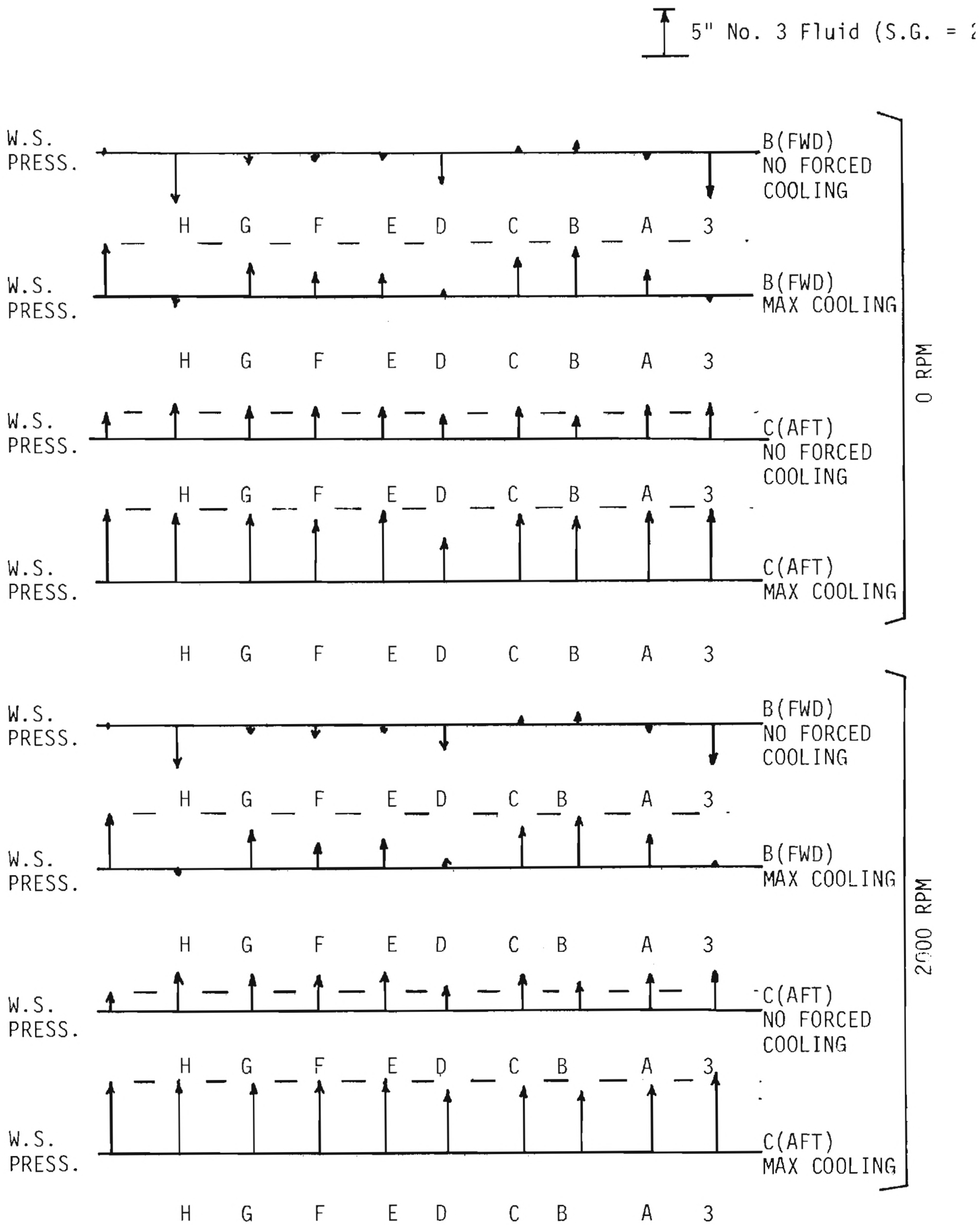

Figure 8. Cross Flow Pressures. (Run M)

(no forced cooling and maximum forced cooling). Again the average wheelspace pressure is shown on the left hand side for each case. In each case comparison of the local rim flow static pressure and the wheelspace pressure will indicate whether the flow is into the wheelspace or out of the wheelspace. Even at 2000 RPM and maximum coolin flow there exists both in and outward flow on the aft seal and on the forward seal while most flow is outward, at least one location appears to have approximately zero flow.

The above data show that the non-uniformity introduced in the rim flow by the inlet ports and the stator blades causes the circumferential variation of the seal pressure drop and flow. The possibility of hot gas inflow persists at high wheel speed even with substantial cooling air flow in the wheelspace.

V. CONCLUSIONS

The major conclusions of this phase of the wheelspace program are:

1. A test facility has been constructed and shown to operate which simulates all the salient features of an actual turbine wheel sealing system which include: hot rim flow, turning of rim flow, variable wheel speed, variable cooling flow. The facility is adequately instrumented to measure average flowrates, and local pressures and temperatures. The system seal geometry can be varied.
2. The system global behavior is as expected in an actual product turbine. The system detailed behavior - the circumferential variation of seal pressure drop - is assumed to simulate production machine behavior.
3. Preliminary baseline system behavior with respect to wheelspace temperature and pressure have been obtained and presented for different wheelspeeds and cooling flows.
4. Circumferential variation in main flow pressures is the dominate cause of hot gas flow into the wheelspace even at relatively high cooling flow rates. The circumferential variation in the main flow is the result of discrete inlet geometry and stator blading.
5. In the next phase of this program it will be necessary to record more circumferentially detailed pressure and temperatu information in the seal area.

APPENDIX A

TABLES

Table A1. Temperatures.

T/C	TEMP	B-1	B-2	B-3	B-4	B-5	B-6	B-7	C-1*	C-2	C-3	C-4	C-5	C-6	C-7	C-8	C-9	C-10	C-11	C-12	C-13	C-14	D-1*	D-2	D-3	D-4*	D-5*	D-6	D-7	E-1*	E-2*	E-3*	E-4*	E-5*	E-6*	E-11	E-12	E-13	E-14	E-15	F-1*	F-2	F-3*	F-4	F-5	G-1	G-2	G-3	G-4	L-1	L-2	L-3	L-4	L-5
1-2	C73	140	148	128	136	137	142	147	140	180	148	139	137	142	139	140	141	133	133	184	150	147	138	143	174	172	186	140	136	136	133	135	143	180	139	130	132	135	139	144	136	140	146	150	184	137	142	143	145	150	145	144	145	145
1-3	D71	143	146	138	136	137	139	145	140	181	145	134	136	138	138	137	138	133	133	187	147	142	137	140	139	174	187	140	136	128	133	135	135	151	134	130	132	135	137	143	138	138	140	156	184	139	142	144	145	151	145	149	145	145
1-4	C01	215	210	204	202	203	207	212	218	211	212	210	210	212	210	208	206	202	201	217	211	212	209	209	210	216	218	204	198	212	211	211	215	215	207	213	212	209	211	213	207	210	211	215	218	211	211	209	210	218	210	225	208	210
1-5	C74	133	143	138	136	137	139	145	187	179	142	141	136	138	139	135	140	133	136	185	145	142	134	140	137	174	184	140	136	137	136	135	145	137	138	130	132	135	139	147	136	130	140	167	184	139	142	143	145	150	145	147	145	145
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1-7	C84	175	146	133	136	137	139	145	170	167	142	137	136	138	138	134	136	135	134	173	176	142	135	140	139	163	173	140	137	130	132	132	140	155	134	130	132	135	139	144	136	138	140	149	174	139	142	144	145	146	145	147	145	145
1-8	C81	173	145	138	136	137	139	145	169	167	142	134	136	138	137	140	135	133	133	170	145	142	135	140	139	162	170	140	136	128	128	131	134	137	134	130	132	135	139	143	136	138	140	147	172	137	142	144	145	150	145	149	145	145
1-9	E81	164	142	139	136	137	139	145	157	157	142	134	136	138	136	135	133	133	132	161	143	141	135	140	139	156	163	140	136	128	128	131	135	137	132	130	132	135	139	143	136	138	139	148	168	139	142	144	145	150	145	147	145	145
1-10	C83	166	143	138	136	137	139	144	164	161	142	134	136	138	137	134	134	135	133	164	145	142	135	140	139	158	167	140	136	125	128	128	134	137	134	130	132	133	136	138	136	138	140	149	169	139	142	144	145	147	145	147	145	145
1-11	D82	170	143	138	136	137	139	144	166	165	142	134	136	138	139	136	134	135	132	169	145	142	135	140	140	161	170	140	136	128	129	129	134	137	134	130	130	135	139	141	136	138	140	149	172	139	142	144	145	150	145	147	145	145
1-12	F71	142	141	144	144	145	148	151	129	129	133	134	136	137	139	184	191	199	201	192	198	197	131	137	137	139	142	184	194	130	132	131	137	137	143	130	134	137	139	141	145	140	140	144	149	142	145	145	147	152	145	147	145	145
2-1	F73	141	141	142	135	140	141	150	118	131	134	136	137	138	138	184	191	199	201	192	198	197	131	137	138	140	142	184	194	127	132	132	138	140	149	130	136	136	142	140	145	141	142	146	150	140	142	145	147	156	146	145	144	145
2-3	A71	141	141	143	138	140	144	149	124	127	128	134	132	135	134	182	189	197	199	193	198	195	128	135	135	136	140	184	193	122	130	130	133	137	144	130	132	135	138	140	140	137	139	142	146	140	142	143	145	152	146	145	144	145
2-4	B71	141	141	143	138	140	144	149	118	123	128	130	134	133	134	179	184	192	194	192	196	195	128	134	135	136	140	182	190	122	130	130	133	137	144	130	132	135	138	140	145	137	139	142	146	140	142	143	145	152	146	145	144	145
2-5	B74	134	137	143	142	140	141	149	118	122	126	130	132	135	134	171	178	188	190	184	188	188	128	134	135	136	140	175	185	121	128	130	133	137	146	130	132	135	135	140	135	137	139	142	146	140	142	143	145	151	146	145	144	145
2-6	F82	129	135	139	136	137	144	144	118	121	126	130	131	132	132	157	165	176	179	173	175	175	123	132	133	132	135	166	176	120	125	125	130	132	139	130	132	135	136	138	135	135	137	140	144	140	142	141	143	148	144	145	144	145
2-7	A81	133	136	140	138	140	144	146	124	123	128	130	132	134	134	163	174	185	187	182	186	185	128	134	135	136	140	172	183	124	129	128	134	136	144	130	132	135	138	140	137	136	138	151	146	140	142	143	145	150	146	145	144	145
2-8	F33	133	137	142	136	140	144	149	118	123	128	130	132	135	138	162	169	180	182	176	178	178	128	134	135	136	140	168	179	125	130	130	133	137	146	130	132	135	138	140	135	137	139	142	146	140	142	143	145	151	146	145	144	145
2-9	B84	140	139	142	141	140	144	148	124	123	128	130	132	135	138	178	184	192	194	191	198	193	128	134	135	136	140	182	190	125	130	130	133	137	151	130	132	135	138	140	135	137	139	142	146	140	142	143	145	152	146	145	144	145
2-10	A81	133	137	141	138	140	144	155	118	123	128	130	132	135	134	168	174	184	186	181	184	184	128	134	135	136	140	172	183	122	130	130	133	137	144	130	132	135	138	145	135	137	139	142	146	140	142	143	145	152	146	145	144	145
2-11	E71	186	141	141	138	141	144	159	137	178	128	138	137	141	134	156	137	176	135	184	148	144	137	143	140	172	187	140	138	132	135	135	140	143	136	130	132	138	138	145	135	137	137	147	182	140	142	143	145	152	146	145	144	145
2-12	C66	186	143	141	138	140	144	155	212	211	184	164	161	170	166	166	162	156	153	214	191	193	162	173	179	201	207	162	155	157	159	159	190	221	160	130	132	138	142	145	155	163	170	185	202	150	160	163	165	151	146	145	144	145
3-1	C64	201	181	162	157	157	163	181	207	205	179	169	158	163	164	160	159	154	151	208	181	184	156	165	171	198	205	163	153	157	158	157	176	189	153	140	145	152	160	170	151	159	166	182	202	178	155	158	164	166	166	160	156	166
3-2	C63	206	175	158	150	152	157	170	212	208	174	155	154	162	160	157	155	150	146	205	179	180	152	162	170	198	210	156	148	151	154	154	181	193	152	138	142	189	158	179	148	157	164	180	203	147	152	154	161	160	162	151	154	164
3-4	C61	201	181	160	150	162	161	187	204	202	176	156	154	160	157	151	151	146	144	205	178	184	152	163	171	192	201	160	148	154	153	153	165	178	154	138	142	148	156	167	146	156	164	177	197	146	152	154	162	157	164	152	152	165
3-5	C53	206	180	162	152	156	153	144	212	209	181	158	156	166	164	160	157	151	146	211	180	185	156	167	174	200	210	158	149	154	157	158	136	198	154	140	144	151	164	184	151	159	166	182	204	158	154	157	165	165	166	154	156	167
3-6	C51	206	179	159	150	152	161	170	207	204	172	156	152	160	157	151	150	146	143	208	182	182	152	162	170	174	209	156	146	151	151	151	162	180	150	138	142	148	155	165	148	156	164	178	199	148	152	154	162	158	165	152	153	165
3-7	C43	208	174	168	162	162	158	194	216	215	194	165	166	176	177	179	161	154	150	217	194	174	154	173	181	204	213	163	153	160	167	167	203	211	158	141	148	158	175	201	157	164	170	184	206	152	162	163	167	172	161	160	164	171
3-8	C41	206	180	164	156	159	164	174	212	208	184	163	160	166	165	160	158	153	150	214	189	187	161	165	170	198	208	163	153	159	160	160	175	190	154	141	141	154	162	174	154	159	166	178	201	151	160	160	165	167	168	158	148	167
3-9	C33	210	158	173	169	168	172	198	218	217	200	179	174	164	189	179	172	165	160	217	202	201	169	176	184	211	216	176	162	174	181	181	206	213	171	150	158	170	190	206	161	168	173	166	207	141	168	183	173	176	176	170	169	176
3-10	C24	216	209	198	171	193	197	212	220	220	210	192	192	198	198	201	194	185	180	222	216	216	190	198	203	216	219	198	184	184	188	188	210	215	186	160	173	191	192	206	187	191	197	206	216	174	184	188	191	192	198	187	185	166
3-11	C23	222	217	205	197	200	207	218	226	226	200	206	206	213	215	208	200	188	180	227	221	221	204	211	215	224	221	225	188	203	212	213	222	224	190	167	184	198	217	224	198	204	210	216	224	187	195	199	204	209	208	157	195	228
3-12	C21	220	209	195	189	190	177	210	224	222	207	190	191	195	194	194	188	183	177	225	215	214	188	196	201	217	221	195	180	185	188	188	203	213	183	162	172	182	190	201	185	190	197	206	219	172	182	184	193	200	198	185	183	196
4-1	C11	219	209	197	190	192	198	206	224	222	207	191	192	176	174	195	170	184	177	225	215	214	170	196	202	218	222	176	182	185	187	188	205	214	183	163	173	182	171	202	186	191	198	207	218	173	182	184	193	201	199	186	184	198
4-2	C31	219	209	197	190	192	198	206	213	210	192	170	167	169	170	166	164	159	156	215	195	194	167	170	174	203	208	171	159	165	165	163	180	194	165	163	173	182	191	202	157	163	169	180	200	153	164	168	168	201	199	186	184	158
4-3	B61	156	162	165	166	166	168	171	130	135	139	141	143	147	145	210	214	219	220	227	220	222	136	145	150	153	156	201	214	132	142	138	144	146	160	134	138	142	145	148	159	154	156	160	164	149	155	154	156	167	165	165	155	159
4-5	B63	160	165	165	166	163	168	171	140	144	148	149	152	154	149	211	214	220	220	220	220	226	142	152	157	160	162	203	213	135	140	141	151	154	176	139	135	147	154	158	167	161	161	168	168	153	160	160	163	170	164	162	158	162
4-6	B64	160	163	165	165	166	167	170	135	139	144	145	150	154	149	210	215	220	220	216	218	213	141	150	153	157	160	205	213	135	140	141	147	149	176	137	132	145	154	153	173	161	160	162	167	152	158	158	162	163	162	158	155	162
4-7	B51	158	162	165	165	166	167	171	130	135	139	141	145	149	145	212	215	220	220	217	220	220	137	146	150	155	157	203	213	132	136	138	144	146	162	134	138	142	145	148	162	155	158	161	165	149	155	156	157	166	164	165	156	160
4-8	B53	160	162	165	163	166	167	171	142	146	150	149	152	158	152	213	217	221	220	219	221	220	143	152	157	161	163	205	214	138	142	146	153	155	176	139	132	145	155	160	170	161	161	164	167	154	160	160	162	170	165	165	158	158
4-9	B41	160	162	165	163	166	167	171	135	139	143	145	155	153	147	215	218	222	220	211	223	220	141	152	157	158	165	205	215	138	140	144	147	150	176	159	132	145	149	152	165	157	161	164	167	154	160	160	162	170	167	165	165	164
4-10	B43	167	170	170	170	170	173	176	149	155	160	158	164	167	160	218	222	225	225	220	224	222	149	157	162	167	169	214	220	144	149	160	159	161	199	145	152	156	161	167	179	166	167	170	174	160	165	165	168	179	170	167	165	169
4-11	B44	164	169	170	170	170	167	176	142	147	152	153	157	161	155	217	220	222	223	220	223	224	144	153	157	162	165	210	219	138	142	144	150	152	197	141	136	150	154	158	179	166	165	168	171	157	161	162	165	171	167	165	162	166
4-12	B31	160	166	165	167	167	170	172	136	141	147	149	155	156	152	215	218	223	223	220	223	223	144	151	154	160	162	206	216	138	142	144	150	152	180	141	136	150	154	157	169	161	161	165	169	154	157	160	162	171	168	166	160	164
5-1	B33	170	171	170	170	170	173	177	150	157	162	162	166	168	166	221	222	225	226	222	225	225	147	157	162	169	170	211	221	149	154	156	164	167	203	150	157	163	168	172	182	166	167	170	175	159	165	165	168	175	171	163	166	170
5-2	B21	181	183	185	183	184	186	189	152	154	157	158	162	165	163	223	224	228	227	225	223	223	152	161	164	169	176	217	223	149	153	155	161	154	202	151	157	160	184	167	194	170	172	175	182	162	167	168	171	184	180	176	171	176
5-3	B23	197	173	191	187	191	194	197	168	171	176	176	177	181	181	228	228	231	230	228	227	221	164	172	176	180	187	227	221	165	171	172	180	183	220	156	175	180	184	189	209	182	183	189	190	173	182	183	186	191	187	182	180	184
5-4	B24	195	199	192	191	192	195	198	162	163	163	166	169	173	170	226	226	229	229	227	228	228	156	165	169	174	183	225	225	152	153	156	163	155	220	152	159	164	169	172	211	175	178	179	186	165	170	172	176	191	184	176	174	178
5-6	B11	184	185	185	184	183	182	191	155	155	158	160	162	165	163	223	224	227	226	225	227	221	153	161	164	169	173	220	224	149	154	155	161	154	202	151	156	160	163	167	197	170	174	176	182	162	167	168	170	184	181	176	171	176
5-7	A01	213	214	214	214	213	212	212	223	222	224	225	224	225	205	221	220	220	218	216	213	213	222	220	221	222	222	221	214	231	230	230	229	226	222	226	226	224	224	223	222	223	223	223	221	225	224	226	223	232	225	224	221	227
5-8	D01	220	219	214	214	214	215	218	221	220	216	214	215	217	215	223	220	217	219	215	217	220	211	214	216	219	217	222	216	215	216	216	218	218	217	214	212	212	213	213	220	214	218	219	221	211	213	212	214	223	217	212	216	216
5-9	B03	220	220	219	219	219	219	218	226	226	227	228	226	226	229	223	222	224	224	230	219	218	223	223	222	223	223	222	218	230	230	225	227	228	226	226	226	228	228	226	233	232	223	232	224	222	222	223	221	222	220	220	221	220
5-10	C03	216	214	208	203	207	211	213	221	220	219	214	212	216	220	209	202	198	193	214	210	213	211	229	216	218	214	203	191	222	224	234	234	224	226	215	213	217	221	222	210	214	217	218	219	214	213	212	213	214	212	207	212	213
5-11	B01	224	225	224	224	225	224	224	230	231	230	232	231	232	231	228	228	228	220	225	223	223	229	229	230	236	231	230	223	233	233	234	235	231	224	230	229	228	228	228	227	230	230	230	229	229	229	229	223	232	228	227	229	228
6-1	B04	220	220	220	221	221	220	220	223	224	224	223	225	225	225	222	222	223	224	220	218	218	220	219	220	220	221	224	220	225	225	224	224	224	224	221	221	221	222	222	225	224	224	224	224	222	222	222	222	222	225	213	218	217
6-2	C04	220	219	209	202	206	211	214	221	221	217	216	214	217	215	204	203	194	192	221	214	216	214	214	216	217	217	205	194	[illegible]	220	221	221	222	196	214	216	217	218	219	212	218	217	219	221	218	218	217	217	220	225	213	218	217
6-10	AMBIENT																																			86	84	81	82	82										89	92	94	88	92
6-11	CROSS								242	245	243	244	245	241	240	235	237	236	238	235	234	230	241	239	240	238	242	238	234	244	244	242	243	241	241	244	241	241	240	244	238	240	238	240	239	238	237	237	238	240	238	237	235	237
6-12	COOLING								129	125	127	128	129	130	130					126	126	124	126	128	128	127	130			125	128	128	131	136		127	131	131	132	133	128	130	129	130	131	134	134	133	135	135	134	136	134	137

* Not Steady State

Table A2. Pressures (inches #3 Fluid - SP. GR. = 2.95).

PRESSURE \ RUN	B-7	B-8	E-11	E-12	E-13	E-14	E-15	G-1	G-2	G-3	G-4	G-5	G-6	G-7	H-1	H-2	H-3	H-4	H-5	H-6	I-1	I-2	I-3	I-4	I-5	J-1	J-2	J-3	J-4	J-5	K-1	K-2	K-3	K-4	K-5	K-6	K-7	L-1	L-2	L-3	L-4	L-5	M-1	M-2	M_1-1	M_1-2	N
C04	7.3	5.6	6.3	5.3	5.1	5.2	4.6	8.05	7.95	8.15	7.8	7.5	8.9	7.75	4.6	5.35	6.02	6.8	7.13	7.9	6.25	6.75	6.5	6.2	5.75	4.7	5.7	4.85	5.5	5.0	6.3	7.5	5.7	2.4	5.1	4.3	4.05	8.7	8.0	8.75	8.6	8.1	3.8	5.33	3.8	6.25	5.9
B04	1.0	-.7	2.95	1.8	1.3	.85	.4	3.65	3.05	2.6	1.9	1.05	2.5	1.2	-3.5	.20	.8	1.58	2.0	3.15	3.15	2.6	1.85	1.3	.75	.10	1.35	2.4	.9	2.8	1.4	3.0	.6	1.5	1.1	.1	.05	.5	.55	1.95	2.25	1.9	-.75	2.8	-1.0	3.3	-1.1
C03	7.9	6.0	9.05	8.2	7.7	7.35	7.95	10.4	10.3	9.85	9.3	8.35	9.25	8.15	5.05	5.75	6.3	6.9	7.18	8.52	8.03	7.4	6.9	6.55	6.05	4.6	6.05	7.55	5.7	8.0	6.8	8.2	6.2	5.5	5.0	4.2	4.1	5.55	8.5	9.5	9.6	8.7	3.9	7.8	4.1	8.6	3.9
B03	-4.0	-5.8	-7.7	-2.8	-3.45	-4.0	-4.28	-7.85	-2.15	-2.5	-2.85	-3.5	0.0	0.0	-4.25	-3.9	-3.35	-2.6	-2.1	-1.02	-.58	-1.25	-2.25	-2.8	-.34	-3.9	-2.3	-1.25	-3.25	-1.0	-1.65	7	-2.6	1.1	.03	-.8	-.8	-.65	-4.3	-2.8	-2.75	-3.8	-4.5	-.4	-4.2	.15	-4.7
C13	6.4	4.3	8.73	7.65	7.0	6.42	6.0	9.3	8.7	8.2	7.55	6.6	8.1	6.7	3.15	4.45	5.10	5.93	6.22	7.6	7.35	6.85	6.0	5.5	4.9	3.7	3.45	7.1	4.9	7.55	5.45	7.1	4.7	4.6	4.2	3.35	3.15	4.5	6.0	8.1	8.0	7.0	3.6	7.5			
C23	7.0	4.9	8.6	7.41	7.07	6.6	6.2	9.6	9.05	8.6	8.05	7.05	8.25	7.1	4.12	4.9	5.98	6.1	6.33	7.68	7.37	6.9	6.2	5.75	5.2	4.0	5.6	7.0	5.13	7.45	5.9	7.25	5.2	5.0	4.5	3.8	3.65	5.1	7.3	8.3	8.4	7.45	3.35	7.4			
C24	6.4	4.7	8.35	7.31	6.9	6.55	6.1	8.9	8.45	7.95	7.30	6.5	7.75	6.6	3.85	4.55	5.12	5.73	5.93	6.93	6.70	6.3	5.7	5.3	4.85	3.8	5.3	6.5	4.9	6.75	5.3	6.6	4.7	4.5	4.2	3.5	3.3	4.8	6.7	7.5	7.7	8.35	3.2	6.9			
C33	6.9	4.6	9.07	7.85	7.18	6.60	6.2	9.8	9.15	8.6	7.9	6.9	8.55	7.2	4.0	4.87	5.7	6.52	7.0	8.05	7.78	7.1	6.3	5.78	5.18	3.9	5.7	7.3	5.15	7.9	6.05	7.7	5.2	5.5	4.8	3.9	3.7	5.2	7.2	8.4	8.45	7.35	3.1	7.8			
C43	6.9	4.5	8.75	7.77	7.16	6.6	6.18	9.75	9.15	8.55	7.9	6.9	8.50	7.2	4.01	4.88	5.7	6.5	6.93	7.9	7.63	7.05	6.3	5.78	5.18	3.9	5.7	7.15	5.15	7.7	6.05	7.6	5.2	5.3	4.8	3.9	3.7	5.2	7.2	8.35	8.45	7.35	3.1	7.6			
C44	6.9	4.3	9.0	7.80	7.18	6.6	6.12	9.65	9.1	8.5	7.85	6.75	8.45	7.1	3.85	4.80	5.65	6.43	6.9	7.9	7.68	7.0	6.25	5.75	5.1	3.8	5.7	7.2	5.1	7.8	5.95	7.55	5.05	5.2	4.8	3.8	3.6	5.1	7.1	8.25	8.4	7.25	3.0	7.7			
C53	6.9	4.1	9.15	7.90	7.2	6.6	6.15	9.80	9.1	8.45	7.80	6.65	8.50	7.05	3.58	4.63	5.6	6.48	6.9	8.0	7.8	7.1	6.3	5.7	5.05	3.75	5.7	7.4	5.1	8.0	5.9	7.6	4.9	5.4	4.85	3.7	3.5	5.0	7.0	8.4	8.35	7.2	3.0	7.9			
C64	6.8	3.9	9.0	7.8	7.15	6.6	6.12	9.60	9.0	8.45	7.7	6.5	8.3	7.0	3.35	4.53	5.53	6.33	6.8	7.8	7.6	7.0	6.2	5.7	5.0	3.65	5.7	7.2	5.1	7.8	5.8	7.4	2.8	5.2	4.7	3.6	3.4	4.95	6.9	8.15	8.25	7.1	2.9	7.7			
B13	2.8	1.0	5.8	4.45	3.7	3.2	2.7	6.8	6.25	5.6	4.0	3.7	4.35	3.2	1.25	1.75	2.35	3.05	3.53	5.3	5.4	4.6	3.65	3.05	2.4	1.35	3.1	4.8	2.4	5.35	3.3	5.1	2.5	3.7	2.9	1.85	2.7	2.6	3.3	4.75	4.9	3.7	.3	5.35	.5	5.6	.2
B23	2.7	1.1	5.8	4.4	3.72	3.2	2.68	6.8	6.25	5.6	4.8	3.75	4.45	3.25	1.37	1.88	2.46	3.18	3.63	5.3	5.4	4.6	3.65	3.05	2.45	1.35	3.1	4.8	2.4	5.37	3.35	5.1	2.55	3.65	2.9	1.9	2.75	2.6	3.3	4.75	4.5	3.75	.35	5.15	.6	5.6	.3
B24	2.8	1.0	5.5	4.17	3.53	2.97	2.50	6.7	5.9	5.3	4.5	3.45	4.35	3.10	.95	1.52	2.15	2.92	3.4	5.2	5.3	4.55	3.55	2.95	2.35	1.3	3.0	4.7	2.35	5.25	3.1	4.9	2.2	3.0	2.45	1.4	2.2	2.05	3.1	4.3	4.65	3.5	.25	3.1	.3	5.5	.1
B33	2.8	.9	5.76	4.45	3.70	3.15	2.68	7.3	6.55	5.9	5.0	3.25	4.3	3.05	1.05	1.55	2.15	2.87	3.3	5.7	5.73	4.8	3.8	3.15	2.45	1.35	3.1	4.95	2.4	5.63	3.55	4.6	2.55	3.7	2.9	1.7	2.5	2.4	3.3	4.85	5.1	3.8	.2	5.4	.4	5.9	.1
B43	2.8	.8	5.85	4.4	3.7	3.0	2.67	7.2	6.5	5.85	4.95	3.75	4.25	3.0	.95	1.42	2.05	2.77	3.2	5.65	5.7	4.75	3.75	3.15	2.48	1.3	3.1	4.9	2.4	5.55	3.5	4.5	2.35	3.65	2.9	1.6	2.4	2.3	3.2	4.75	5.05	3.75	.2	5.3	.3	5.9	.1
B44	2.5	.7	5.8	4.4	3.7	3.10	2.65	7.3	6.55	5.85	5.0	3.75	4.35	3.0	.8	1.35	2.0	2.80	3.3	5.65	5.7	4.8	3.8	3.15	2.45	1.4	3.15	4.95	2.4	5.60	3.5	4.5	2.3	3.45	2.7	1.5	2.25	2.1	3.15	4.6	5.05	3.75	.2	5.3	.25	5.7	.1
B53	2.5	.6	6.07	4.3	3.8	3.18	2.70	7.2	6.45	5.75	4.9	3.70	4.05	2.8	.65	1.15	1.8	2.53	3.0	5.55	5.65	4.75	3.75	3.1	2.4	1.3	3.1	4.9	2.4	5.6	3.3	4.4	2.3	3.45	2.7	1.95	2.25	2.1	3.1	4.6	4.15	3.65	.2	5.5	.2	5.55	.1
B64	2.4	.5	5.9	4.4	3.7	3.10	2.63	7.2	6.45	5.75	4.9	3.65	4.1	2.75	.5	1.03	1.7	2.5	3.02	5.55	5.65	4.75	3.75	3.1	2.35	1.3	3.1	4.9	2.4	5.6	3.25	4.4	2.2	3.3	2.6	1.3	2.1	1.9	3.0	4.5	4.9	3.6	.2	5.35	.1	5.85	.1
E73	6.7	3.3	8.95	7.8	7.15	6.6	6.12	9.6	9.0	8.35	7.55	6.3	8.25	6.9	3.0	4.33	5.4	6.3	6.75	7.15	7.6	6.95	6.2	5.6	4.9	1.5	5.65	7.2	5.1	7.8	5.6	7.4	4.5	5.1	4.6	3.4	3.3	4.85	6.8	8.1	8.2	6.7	2.7	7.7	2.2	7.8	2.6
E74	6.7	3.6	8.95	7.8	7.15	6.6	6.12	9.6	9.0	8.4	7.6	6.3	8.3	6.95	3.0	4.33	5.4	6.3	6.75	7.75	7.6	6.95	6.2	5.6	4.9	1.5	5.65	7.2	5.1	7.8	5.7	7.4	4.5	5.1	4.6	3.5	3.3	4.85	6.7	8.1	8.2	6.95	2.7	7.7	2.2	7.8	2.6
E7.34	6.7	3.3	8.95	7.8	7.15	6.6	6.12	9.6	9.0	8.35	7.6	6.3	8.3	6.9	3.0	4.33	5.4	6.3	6.15	7.75	7.6	6.95	6.2	5.6	4.9	1.5	5.65	7.2	5.1	7.8	5.7	7.4	4.5	5.1	4.6	3.4	3.2	4.8	6.5	8.1	8.2	6.35	2.7	7.7	1.9	7.8	2.6
E7.64	6.7	3.3	8.75	7.8	7.15	6.6	6.12	9.6	9.0	8.35	7.55	6.25	8.3	6.9	3.0	4.33	5.4	6.3	6.75	7.75	7.6	6.95	6.2	5.6	4.9	1.5	5.65	7.2	5.1	7.8	5.4	7.2	4.2	4.8	4.3	3.1	2.9	4.45	6.5	7.9	8.1	6.7	2.7	7.7	1.9	7.8	2.6
E84	6.7	3.3	8.95	7.8	7.15	6.6	6.12	9.6	9.0	8.35	7.55	6.25	8.3	6.9	3.0	4.33	5.4	6.3	6.75	7.75	7.6	6.95	6.2	5.6	4.9	1.5	5.65	7.2	5.1	7.8	5.6	7.4	4.5	5.0	4.5	3.3	3.1	4.65	6.6	8.0	8.2	6.8	2.7	7.7	1.9	7.8	2.6
F73	2.3	.4	5.8	5.4	3.6	3.1	2.65	7.05	6.35	5.7	4.8	3.0	3.9	2.6	.38	.90	6.55	2.3	2.8	5.4	5.5	4.6	3.65	3.05	2.3	1.3	3.0	4.8	2.35	5.4	3.2	5.2	2.1	3.2	2.5	1.2	1.0	1.9	2.9	4.4	4.8	3.5	.2	5.3	0.0	5.7	.1
F74	2.3	.4	5.8	5.4	3.6	3.1	2.65	7.05	6.35	5.7	4.8	3.0	3.9	2.6	.38	.90	6.55	2.3	2.8	5.4	5.5	4.6	3.65	3.05	2.3	1.3	3.0	4.8	2.35	5.4	3.2	5.2	2.1	3.2	2.5	1.2	.95	1.8	2.9	4.4	4.8	3.5	.1	5.25	0.0	5.7	.1
F7.34	2.3	.4	5.8	5.4	3.6	3.1	2.65	7.05	6.3	5.7	4.8	3.0	3.85	2.55	.38	.90	6.55	2.3	2.8	5.4	5.5	4.6	3.65	3.05	2.3	1.3	3.0	4.8	2.35	5.4	3.2	5.2	2.1	3.2	2.5	1.2	.9	1.8	2.9	4.4	4.8	3.5	.2	5.25	0.0	5.7	.1
F7.64	2.3	.4	5.8	5.4	3.6	3.1	2.65	7.00	6.3	5.65	4.8	3.0	3.8	2.5	.38	.90	6.55	2.3	2.8	5.4	5.5	4.6	3.65	3.05	2.3	1.3	3.0	4.8	2.35	5.4	3.2	5.2	2.0	3.2	2.5	1.2	.9	1.8	2.9	4.4	4.8	3.5	.2	5.25	0.0	5.7	.1
F84	2.3	.4	5.8	5.4	3.6	3.1	2.65	7.00	6.3	5.6	4.25	3.0	3.85	2.45	.38	.90	6.55	2.3	2.8	5.4	5.5	4.6	3.65	3.05	2.3	1.3	3.0	4.8	2.35	5.4	3.2	5.2	2.1	3.2	2.5	1.2	.9	1.8	2.9	4.4	4.8	3.5	.2	5.25	0.0	5.7	.1
COA																																											3.45	7.2	5.7	7.0	
COB																																											2.55	6.25	2.8	6.2	
COC																																											3.45	7.05	3.3	7.0	
COD																																											2.75	4.65	2.45	6.35	
COE																																											3.6	7.2	3.9	7.9	
COF																																											3.5	6.75	3.8	7.5	
COG																																											3.5	7.15	3.8	7.4	
COH																																											3.85	7.05	4.0	7.7	
COJ																																															4.6
COK																																															3.5
COL																																															3.6
COM																																															3.15
BOA																																											-.8	2.7	-.65	3.2	
BOB																																											1.05	5.0	1.15	5.3	
BOC																																											.1	4.0	.6	4.2	
BOD																																											-3.15	.7	-2.85	1.0	
BOE																																											-.6	2.75	-.35	3.0	
BOF																																											-1.55	2.55	-1.2	2.8	
BOG																																											-.7	3.4	-.3	3.7	
BOH																																											-5.05	-1.0	-4.7	-.6	
BOJ																																															.15
BOK																																															-5.8
BOL																																															-.8
BOM																																															-.75

APPENDIX B

PHOTOGRAPHS OF WHEELSPACE APPARATUS

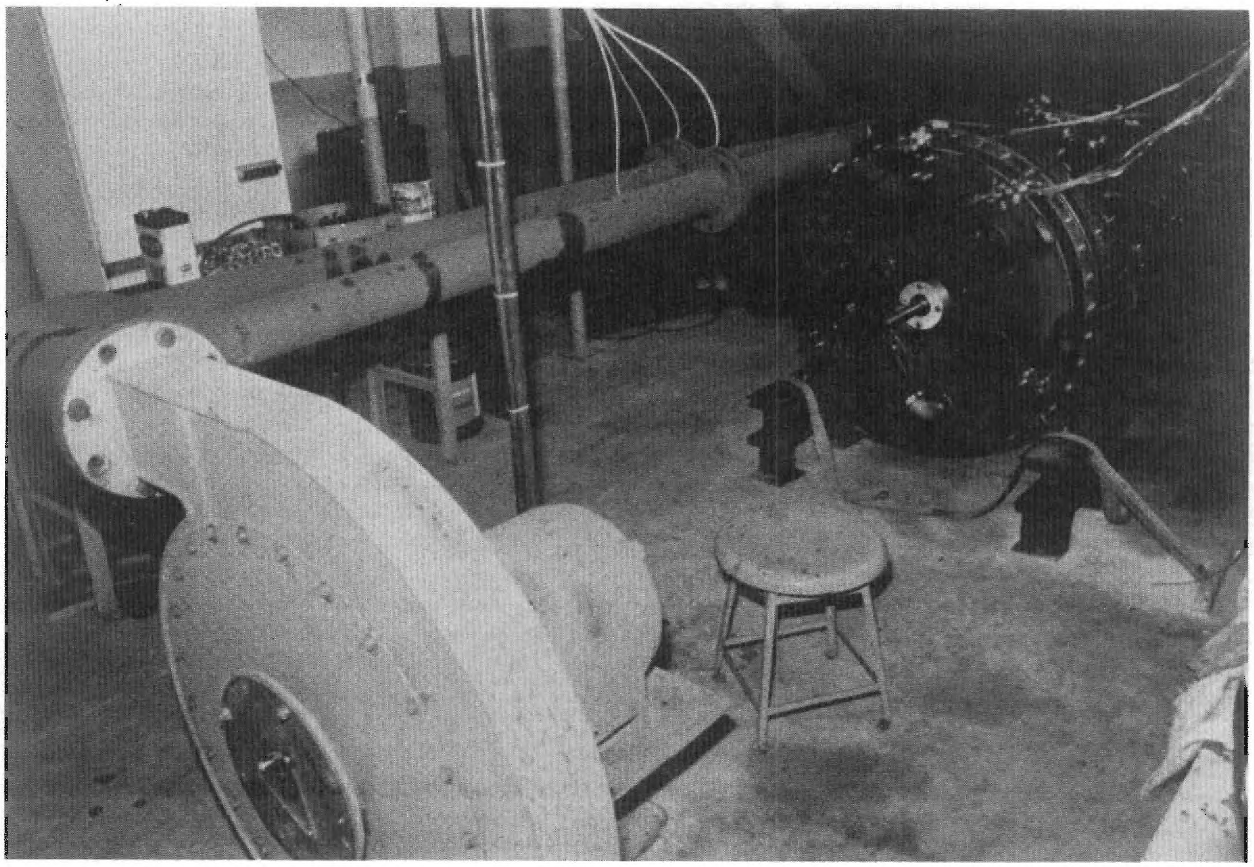


Figure B1. Overview of Wheelspace Test Facility. Wheelspace Apparature right background viewed from aft side, left foreground is blower to supply cooling air, drive engine behind wheelspace apparatus.

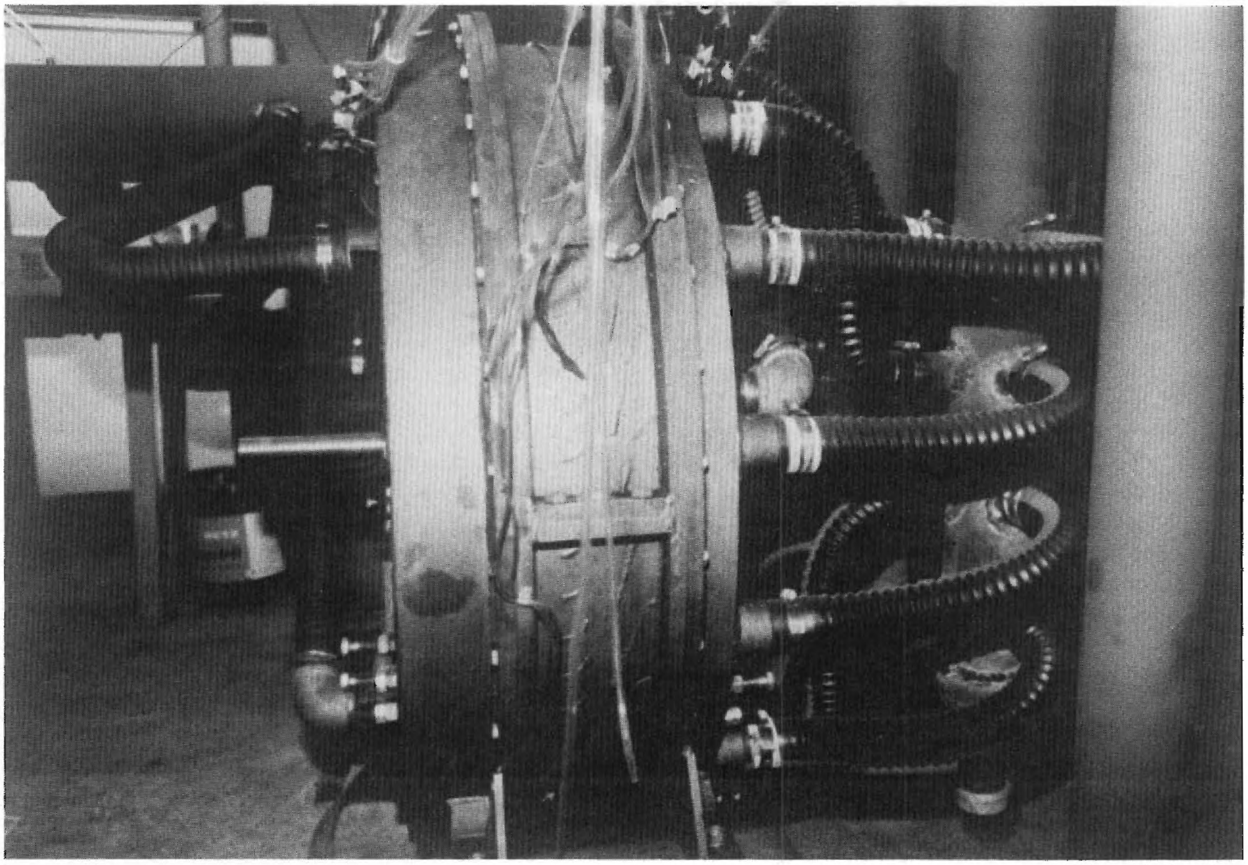


Figure B2. Side View of Wheelspace Test Apparatus. Rim flow enters on right and exits on left, forward wheelspace on right and aft on left, drive engine is on right.

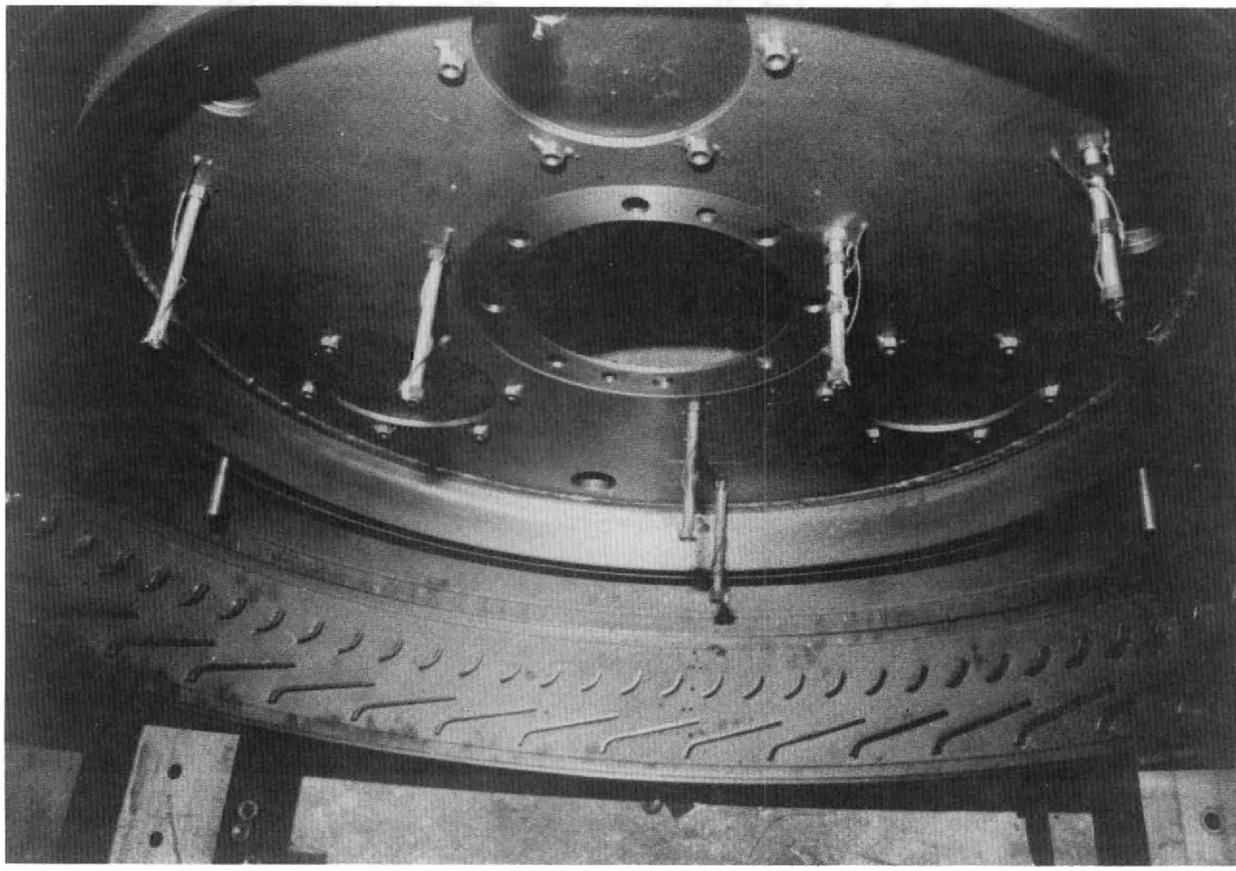


Figure B3. Inside View of Aft Wheelspace with Wheel Removed. Three cooling flow inlets (bottom center, top left and middle right), wheelspace thermocouples mounted threaded rod projecting from surface.

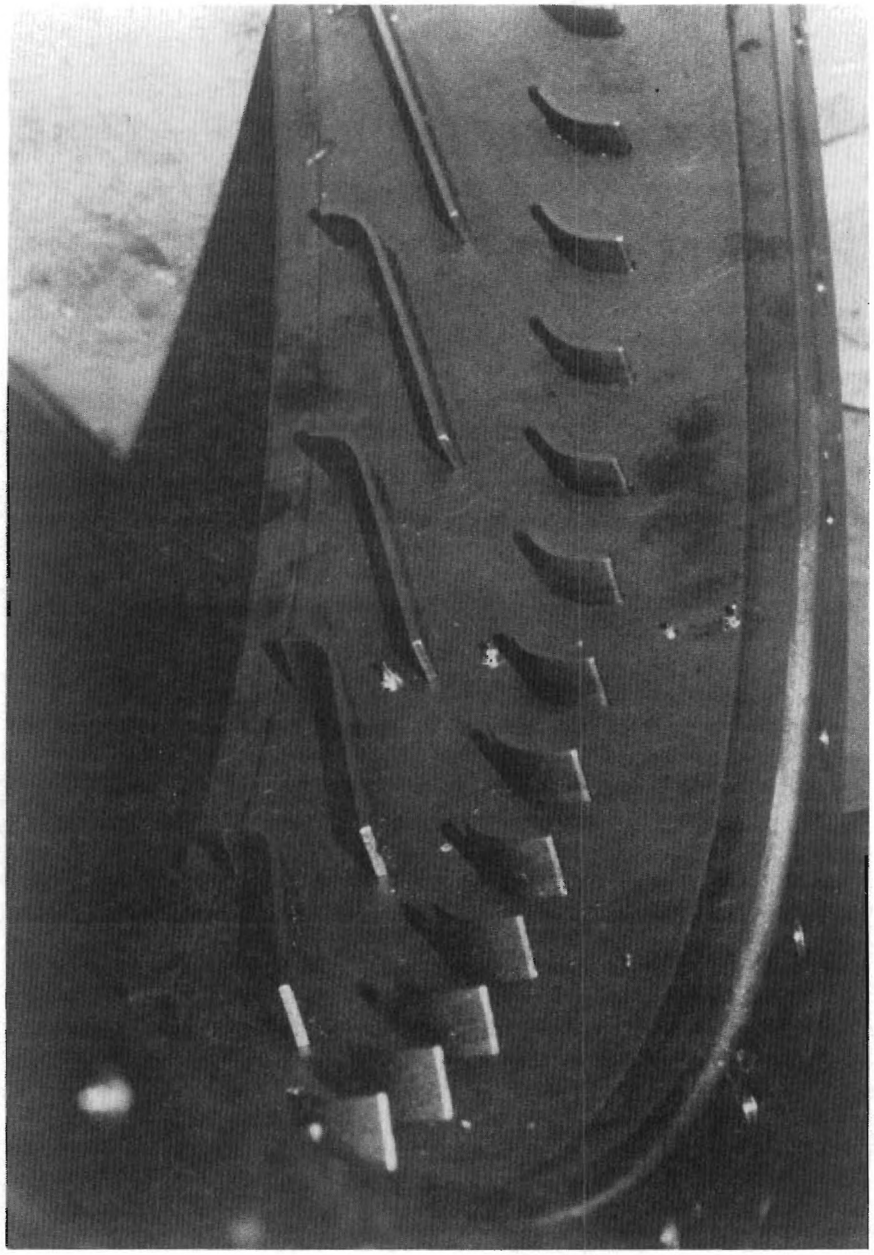


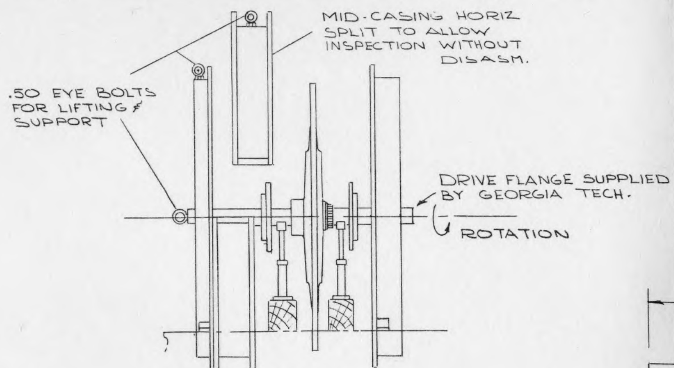
Figure B4. Rim Cover with Blades and Rim Flow Instrumentation. Nozzle blades on left and wheel turning blades on right, rim flow from left to right, rim flow instrumentation along a horizontal line in middle of picture.

Figure B5. Seal Area Instrumentation. Radically distributed pressure taps and thermocouples in seal area typical of #3 circumferential position (forward or aft).

APPENDIX C

MECHANICAL DRAWINGS OF WHEELSPACE APPARATUS

No. 10-5-523	Wheelspace Test Rig
No. 10-5-523-1	Wheelspace Test Rig
No. 10-5-523-2	Wheelspace Test Rig
No. 10-5-523-3	Wheelspace Test Rig
No. 10-5-523-4	Wheelspace Test Rig



WHEEL SPACE TEST RIG DISASM

NOTES:
* THESE ITEMS TO BE ASM PER TESTING INSTRUCTIONS

DIRECTION OF ROTATION TO SUIT GEORGIA TECH. DRIVE & IS OPPOSITE FROM G.T. STANDARD

QTY	PT NO	NAME	IDENT
8	19	BOLT	.50-13×1.00LG ALLOY ST'L
16	20	BOLT	.625-11×1.00LG ALLOY ST'L
4	21	BOLT	.25-20×.75LG ALLOY ST'L
72	22	BOLT	.375-16×1.25LG ALLOY ST'L
6	23	BOLT	.50-13×6.00 (5.50" OF TH'DS) ALLOY ST'L
6	24	BOLT	.50-13×3.50 (3.00" OF TH'DS) ALLOY ST'L
18	25	NUT-HEX	.50-13 ALLOY ST'L
64	26	SCREW-SET	#6-32×.375LG - ALLOY STEEL
20	27	BOLT-12 PT	#10-32×1.00 LG ALLOY ST'L
20	28	NUT-12 PT	#10-32 ALLOY ST'L
1	29	PACKING	VENDOR: John MANVILLE DESCRIPTION: CHEMPAC 2009 .25×.25×110LG

UNLESS OTHERWISE SPECIFIED USE THE FOLLOWING:—

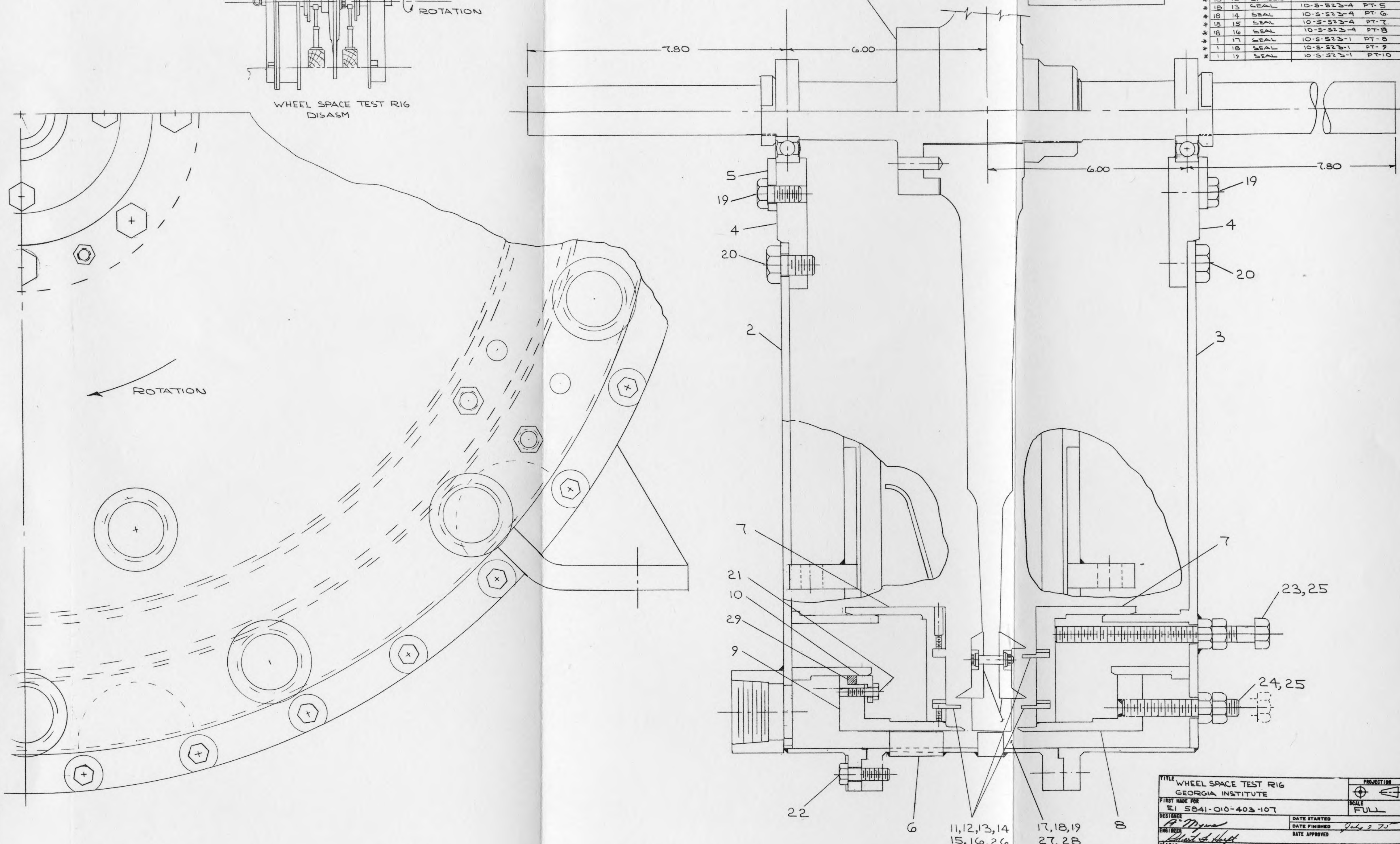
APPLIED PRACTICES	SURFACES	TOLERANCES ON MACHINED DIMENSIONS: FRACTIONS	DECIMALS	ANGLES
	✓	±	±	±

TITLE

CONT ON SHEET SH NO

FIRST MADE FOR

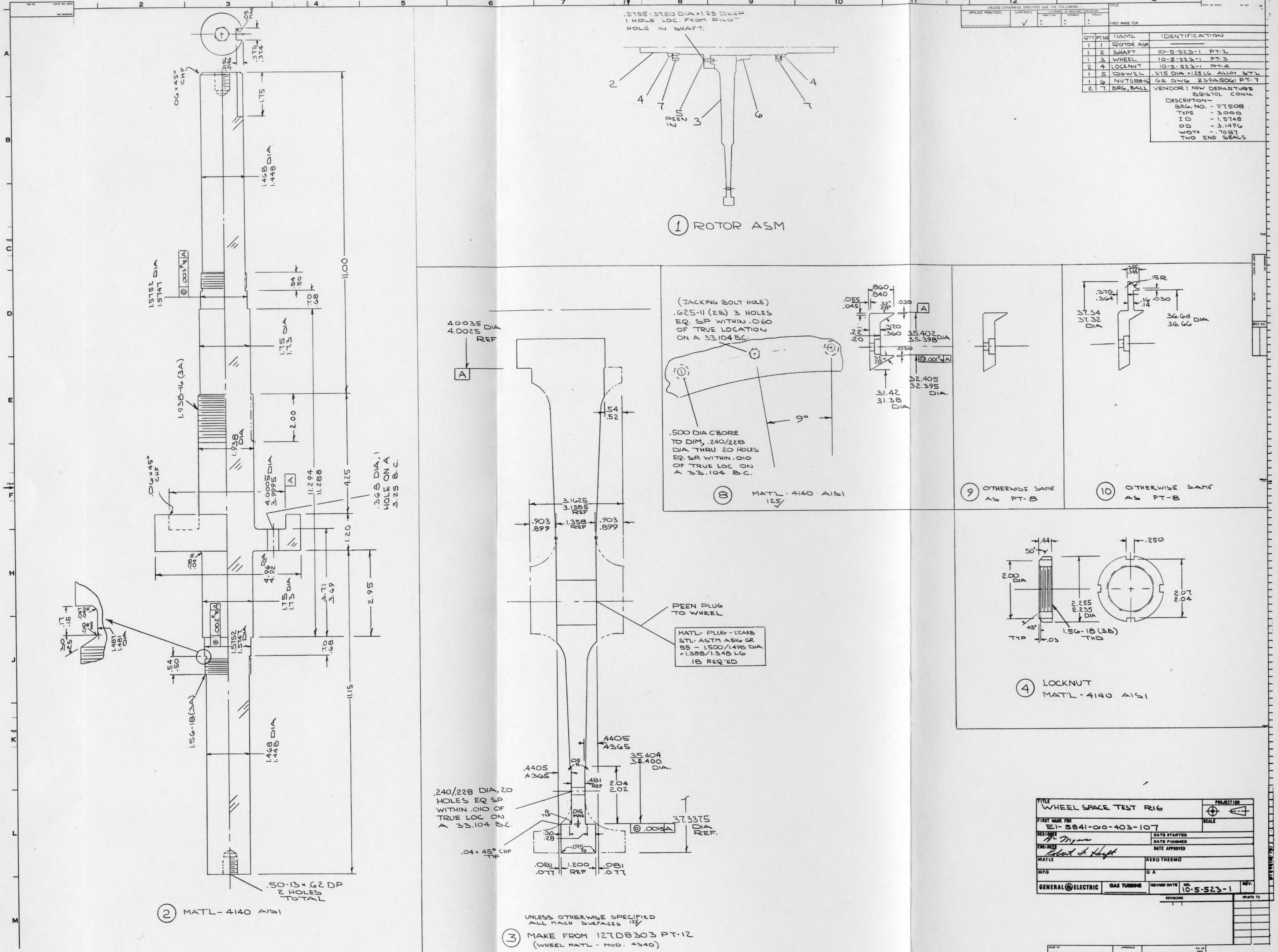
	QTY	PT NO	NAME	IDENTIFICATION
	1	1	ROTOR ASM	10-5-523-1 PT-1
	1	2	CASE-END	10-5-523-2 PT-2
	1	3	CASE-END	10-5-523-2 PT-3
	2	4	RETAINER-BRG	10-5-523-2 PT4
	2	5	RETAINER-BRG	10-5-523-2 PT-5
	1	6	CASE-MID	10-5-523-3 PT-1
	2	7	RETAINER-SEAL	10-5-523-4 PT-1
	1	8	RETAINER-SEAL	10-5-523-4 PT-2
	1	9	RETAINER-SEAL	10-5-523-4 PT-3
	1	10	RETAINER-PACKING	10-5-523-4 PT-4
*	18	11	SPACER	10-5-523-4 PT-9
*	18	12	SPACER	10-5-523-4 PT-10
*	18	13	SEAL	10-5-523-4 PT-5
*	18	14	SEAL	10-5-523-4 PT-6
*	18	15	SEAL	10-5-523-4 PT-7
*	18	16	SEAL	10-5-523-4 PT-8
*	1	17	SEAL	10-5-523-1 PT-8
*	1	18	SEAL	10-5-523-1 PT-9
*	1	19	SEAL	10-5-523-1 PT-10



TITLE WHEEL SPACE TEST RIG GEORGIA INSTITUTE		PROJECTION
FIRST MADE FOR E1 5841-010-403-107		SCALE FULL
DESIGNER A. Myers	DATE STARTED	
	DATE FINISHED July 9 75	
ENGINEER Robert F. Hoyt	DATE APPROVED	
MATLS	AERO THERMO	
MFG	Q A	
GENERAL ELECTRIC	GAS TURBINE	REVIEW DATE / NO. 10-5-523 / REV.

REVISIONS

PRINTS TO



GENERAL ELECTRIC

QTY	PT. NO	NAME	IDENTIFICATION
1	1	ROTOR ASM	——
1	2	SHAFT	10-5-523-1 PT-2
1	3	WHEEL	10-5-523-1 PT-3
2	4	LOCKNUT	10-5-523-1 PT-4
1	5	DOWEL	.375 DIA × 1.25 LG ALLOY STL
1	6	NUT (1.938-16)	GE DWG 239A5061 PT-7
2	7	BRG, BALL	VENDOR: NEW DEPARTURE BRISTOL CONN. DESCRIPTION— BRG. NO. - 97508, TYPE - 3000, ID - 1.5748, OD - 3.1496, WIDTH - .7087, TWO END SEALS

TITLE: WHEEL SPACE TEST RIG

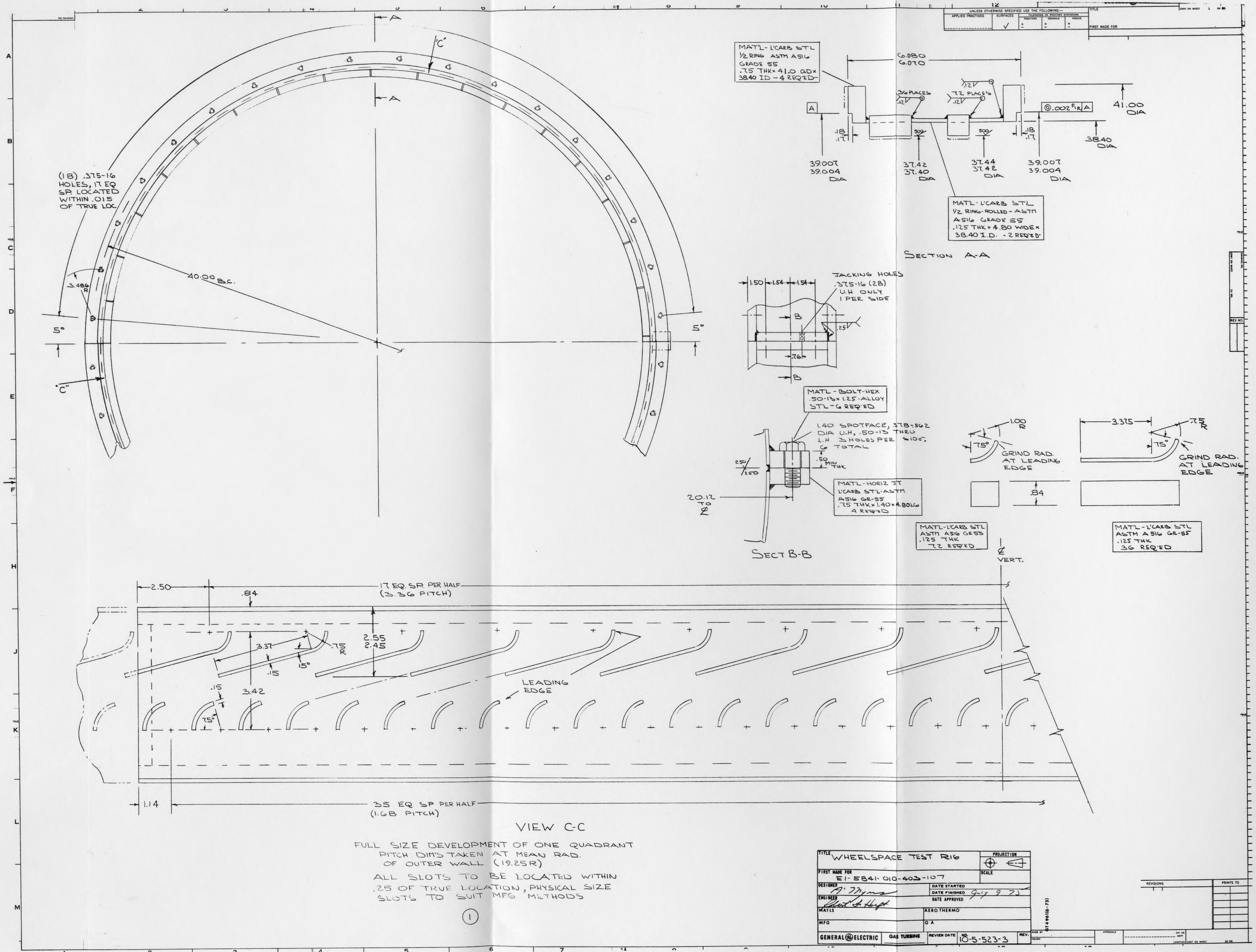
FIRST MADE FOR: E1-5841-010-403-107

DESIGNER: [signature]

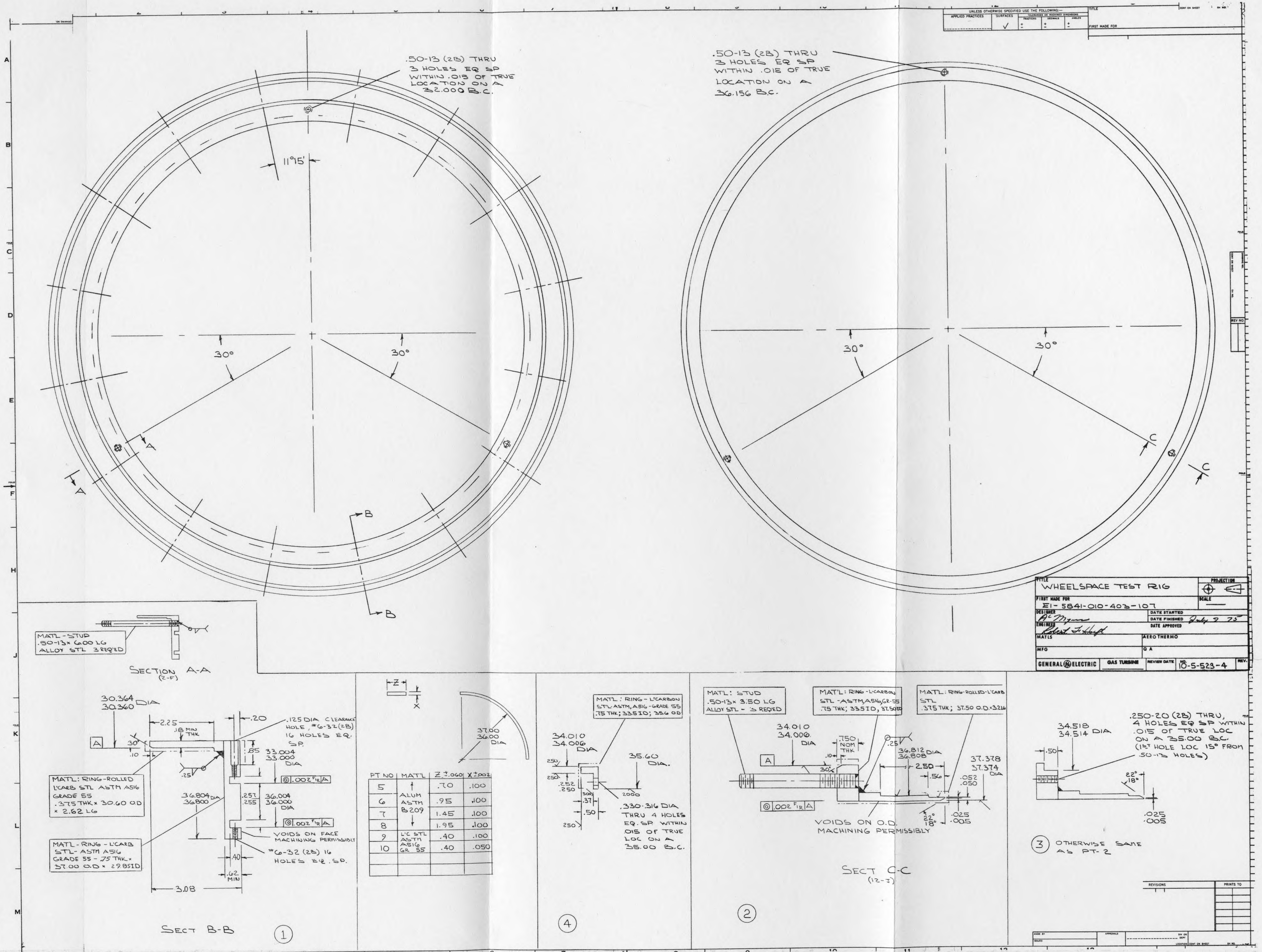
ENGINEER: Robert F. Hoyt

GENERAL ELECTRIC — GAS TURBINE

NO. 10-5-523-1



MATL - L'CARB STL
1/2 RING ASTM A516
GRADE 55
.75 THK × 41.0 OD × 38.40 ID - 4 REQ'D
6.080
6.070
36 PLACES
72 PLACES
41.00 DIA
38.40 DIA
39.007
39.004
DIA
37.42
37.40
DIA
37.44
37.42
DIA
39.007
39.004
DIA
MATL - L'CARB STL
1/2 RING - ROLLED - ASTM
A516 GRADE 55
.125 THK × 4.80 WIDE × 38.40 I.D. - 2 REQ'D
SECTION A-A
(18) .375-16
HOLES, 17 EQ
SP. LOCATED
WITHIN .015
OF TRUE LOC.
40.00 B.C.
3.486 R
5°
5°
"C"
"C"
JACKING HOLES
.375-16 (2B)
U.H ONLY
1 PER SIDE
1.50
1.54
1.54
.76
MATL - BOLT-HEX
.50-13 × 1.25 - ALLOY
STL - 6 REQ'D
1.40 SPOTFACE, 378-362
DIA U.H, .50-13 THRU
L.H 3 HOLES PER SIDE,
6 TOTAL
.50 MIN THK
MATL - HORIZ JT
L'CARB STL - ASTM
A516 GR-55
.75 THK × 1.40 × 4.8066
4 REQ'D
20.12
TO
℄
SECT B-B
1.00 R
75°
GRIND RAD.
AT LEADING
EDGE
.84
MATL - L'CARB STL
ASTM A516 GR55
.125 THK
72 REQ'D
3.375
.75 R
75°
GRIND RAD.
AT LEADING
EDGE
MATL - L'CARB STL
ASTM A516 GR-55
.125 THK
36 REQ'D
℄ VERT.
2.50
17 EQ SP PER HALF
(3.36 PITCH)
.84
3.37
.75 R
15°
.15
2.55
2.45
3.42
.15
75°
LEADING
EDGE
1.14
35 EQ SP PER HALF
(1.68 PITCH)
VIEW C-C
FULL SIZE DEVELOPMENT OF ONE QUADRANT
PITCH DIM'S TAKEN AT MEAN RAD.
OF OUTER WALL (19.25R)
ALL SLOTS TO BE LOCATED WITHIN
.25 OF TRUE LOCATION, PHYSICAL SIZE
SLOTS TO SUIT MFG METHODS
1
TITLE WHEELSPACE TEST RIG
PROJECTION
FIRST MADE FOR E1-5841-010-403-107
SCALE
DESIGNER
DATE STARTED
DATE FINISHED July 9 73
DATE APPROVED
ENGINEER
MATLS
AERO THERMO
MFG
Q A
GENERAL ELECTRIC
GAS TURBINE
REVIEW DATE
NO. 10-5-523-3
REV.
GT4961(6-73)



PT NO	MAT'L	Z ±.060	X ±.002
5	ALUM ASTM B209	.70	.100
6	ALUM ASTM B209	.95	.100
7	ALUM ASTM B209	1.45	.100
8	ALUM ASTM B209	1.95	.100
9	L'C ST'L ASTM A516 GR 55	.40	.100
10	L'C ST'L ASTM A516 GR 55	.40	.050

TITLE: WHEELSPACE TEST RIG
PROJECTION
FIRST MADE FOR: E1-5841-010-403-107
SCALE
DESIGNER: A. C. Myers
DATE STARTED
DATE FINISHED: July 9 75
ENGINEER: Robert F. Hoyt
DATE APPROVED
MATLS
AERO THERMO
MFG
Q A
GENERAL ELECTRIC | GAS TURBINE | REVIEW DATE | NO. 10-5-523-4 | REV.